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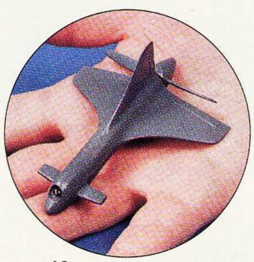

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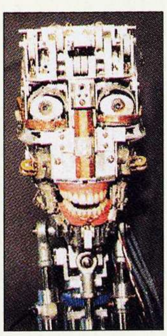

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First Line

By Robert M. White

A MESSAGE TO CONGRESS

The process of innovation is a delicate ecosystem. Don't mess it up.

NOT long ago, U.S. high-tech industries were sagging. The market share of U.S. companies was declining dramatically in everything from semiconductors to consumer electronics to machine tools. The situation was so dire that in April 1991 Intel CEO Andy Grove warned that the United States was in danger of becoming a "technological colony."

Three years later, the situation had brightened measurably. For example, U.S. companies dominated the markets for microprocessors and for cellular phones. The Council on Competitiveness—a nonpartisan forum of chief executives—issued a report in 1994 identifying 22 technologies where the U.S. position had improved, including structural ceramics, display materials, and photonics. Our renewed ability to compete arose from some subtle changes during the early 1990s that made our innovation system much more effective. Unfortunately, the 104th Congress lost sight of this bigger picture and even seemed intent on undermining this progress.

The House, for example, tried to eliminate the National Institute of Standards and Technology (NIST), which has the responsibility of maintaining the nation's physical standards, such as our units of length and time. While the private sector is a beneficiary of standards, industry cannot maintain something as fundamental as the second or the meter. The 104th Congress also discouraged cooperative projects between industry and the national laboratories—collaborations that have helped move the fruits of publicly funded R&D into the commercial sector.

This strategy is counterproductive. After all, much of the recent good news on the rebound of U.S. industry stems from the federally lubricated interaction among the key players in the innovation process—companies and universities. A good example is the manufacture of hard disks for computer data storage, today a $50 billion industry. In the late 1980s, Japan was poised to dominate this market. But in 1990, specifically in response to the opportunity to receive funding from the Department of Commerce, U.S. participants in this industry formed the National Storage Industry Consortium. At the same time, the National Science Foundation established an engineering research center on data storage. This center, at Carnegie Mellon University, has produced more than 100 scientists and engineers with advanced degrees and has pointed the way toward new technologies. The result is that storage densities (the number of digital bits that can be crammed onto each square millimeter of disk) have over the past five years been growing at 60 percent annually—twice the rate of progress the industry considered normal in the preconsortium era.

Most agree that the federal government should maintain an environment conducive to technological innovation. To some this means absolutely no intervention. But the government has responsibilities, such as public health and national defense, that depend on a strong innovation process. The process is a "public good" and as such is entitled to federal support.

In recognizing this responsibility, the government has created a rich array of agencies, programs, and policies. The National Science Foundation (NSF) funds basic research. The Department of Energy maintains national research facilities. The Small Business Administration helps inventors develop ideas. The Commerce Department's Advanced Technology Program funds development too risky for industry. The Department of Defense sponsors about 70 percent of all university research in electronics and computing. The Bayh-Dole Act of 1980 gives universities rights to their federally funded research.

Such diversity enriches the innovation system and enhances its responsiveness, making the United States more competitive. But the system is like a delicately balanced ecosystem. The 105th Congress needs to recognize what its predecessor seemed to disregard: actions taken that affect one element of the fabric may unintentionally tear at the whole. For example, in 1994 a congressional subcommittee seriously entertained a suggestion to drastically reduce Department of Defense funding to universities. This proposal reveals a lack of appreciation that DOD supports nearly as many graduate students as NSF. More recent legislation would have limited the exchange of information generated by publicly funded research in the name of protecting intellectual property and thus make collaboration virtually impossible.

This Congress must avoid undermining the scientific and technological enterprise—and its collaborative and entrepreneurial nature—that drives our economic expansion. What makes this so challenging is that any one member of Congress has control over only a small piece of this mosaic. Each member must look beyond that piece of federal science and technology under his or her committee and assess the impact on the innovation process as a whole.■

ROBERT M. WHITE is University Professor and head of the Department of Electrical and Computer Engineering at Carnegie Mellon University. He served as Under Secretary of Commerce for Technology from 1990 to 1993.

ILLUSTRATION: ROBERT PIZZO

Letters

Canary in a Coal Mine

In "The Case of the Vanishing Frogs" (*TR May/June 1997*), Timothy R. Halliday and W. Ronald Heyer discuss a phenomenon that, although perplexing, is probably indicative of a class of environmental problems that will be increasingly upon us.

We can draw two major points from all of this. First, what initially appears as a simple change (vanishing frogs, in this case) in fact results from multiple factors and ill-understood interactions. That means it would be an error to continue treating changes in isolation from one another and that it is important to be more open to interactive, not just additive, effects. While such realizations should in no way lessen our efforts to stem the sheer destruction of habitat, they mean we will also have to establish more complex environmental research programs, and give priority to environmental monitoring. The President's National Science and Technology Council's Committee on Environment and Natural Resources is seeking to better coordinate efforts to monitor the environment, and Vice-President Gore has called for the committee to provide the basis for an environmental report card on the nation's ecosystems by 2001.

So, vanishing amphibians are not only sending us an important, if as yet hard-to-read, signal about environmental change, they are also telling us to improve environmental research and monitoring.

Thomas E. Lovejoy
Director, Institute for Conservation Biology
Smithsonian Institution
Washington, D.C.

Finding a Reason for Missile Defense

Lisbeth Gronlund and David Wright make a sound case in "Missile Defense: The Sequel" (*TR May/June 1997*). There is little doubt that deploying a U.S. national missile defense system would greatly complicate efforts to reduce the number of Russian nuclear missiles and their hair-trigger alert status. It is less clear what the Chinese reaction would be or if this should be a matter of great concern for U.S. policy makers. These hypothetical responses are certainly worth considering, but I wish the authors had spent more time on the technical capabilities of the proposed systems.

As the authors correctly note, "potential costs to U.S. security might be worth risking if the missile threat were greater and defenses were a more effective means of countering this threat." This is the central point: most conservative proponents of missile defense sincerely believe that the technology is here now to defend the nation effectively from missile attack. The only barrier is the outdated Anti-Ballistic Missile Treaty, they believe, or, an "arms control fetish," as columnist George Will puts it.

Having served for nine years on the professional staff of the House Armed Services Committee and the Government Operations Committee, I know that most members base their decisions on new weapons systems on vu-graphs and projected capabilities. Few hearings are held to compare actual performance with past claims. This is absolutely true for missile defense. Only one hearing was held to evaluate the Patriot missile's performance in the Gulf War, yet the perceived success of the Patriot is the basis of most beliefs that we can rapidly build far superior defenses. As the chief

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investigator of the hearing, I know that the Patriot hit few, if any, of the 45 Scuds it attempted to intercept. (Few realize even today that the explosions they saw in the night skies were not direct hits but were from Patriot proximity fuses detonating as the Scuds sped past the interceptors, or from Patriots self-destructing after missing.)

The military is less sanguine than the politicians about the prospects for effective defense. After recent tests of the improved Patriot system against actual Scud-Bs, which have half the range of the Scuds used in the Gulf War, Lieutenant General Ed Anderson, head of the Army Space and Strategic Defense Command, said, "We are better, but we ain't great yet." After four test failures by the Theater High Altitude Area Defense system (THAAD), officials said that they were being pressed by unrealistic deployment schedules.

Some members of Congress are considering legislation that requires proposed interceptors to pass "fly-before-buy" tests before funding is appropriated. Scientists and technical experts, like the readers of *Technology Review*, should make every effort to explain patiently and repeatedly the limits of current technology, the breakthroughs that would be required for a truly effective missile defense, and the long road ahead before we know if missile defense is technologically possible. Only then will we be able to counter congressional efforts to mandate the deployment of untested, ineffective, and expensive placebos.

JOSEPH CIRINCIONE
Henry L. Stimson Center
Washington, D.C.

Gronlund and Wright provide a thoughtful exposition on today's missile defense debate, where hyperbole often runs rampant. While I agree with much of their argument, their claims that we do not need high-altitude theater missile defenses (TMD) are somewhat overdrawn. Low-altitude defenses cannot provide adequate coverage of all important targets within a theater. Wide-area defenses are needed to protect allied cities and to reduce opponents harboring ballistic missiles armed with weapons of mass destruction.

An option that the authors did not mention exists: airborne boost-phase TMD (specifically the Airborne Interceptor and the Airborne Laser being funded by the Air Force). These defenses attack enemy missiles during their boost phase, when detecting and tracking targets is easier, enemy counter measures are more difficult, and all warheads are destroyed at once. The short boost time makes interception difficult. It has yet to be demonstrated, however, that boost-phase TMD is not technically feasible. Finally, although such systems as they now exist would probably violate the original AMB Treaty, they would not violate it if modified according to suggestions made at the recent Helsinki Summit.

In asking whether the costs, especially the political ones, of ballistic missile defense (BMD) systems outweigh potential benefits, the authors have posed a question that is very difficult to answer. For example, they argue that by creating barriers to nuclear disarmament, BMD will undermine U.S. nonproliferation objectives. While this could be true, one should note that U.S. BMD programs did nothing to inhibit the indefinite extension of the Non-Proliferation Treaty in 1995, as some had previously argued they would.

Moreover, whether defenses interfere with nuclear reductions depends on the

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end point envisioned. Modest TMD deployments should not impede U.S.-Russian reductions to levels around 1,000 strategic nuclear weapons, although they would probably inhibit further lower levels. If zero is the ultimate goal, defenses may be required as insurance against cheating. Regardless, the authors' claim that "U.S. security is best served by irreversible cuts in nuclear weapons to very low numbers—tens or perhaps 100" is debatable.

Engagement with Russia as well as China is important for U.S. security. If unilateral U.S. actions appear hostile to Russia and China, U.S. security could be compromised over the long run. The United States should therefore proceed with TMD in cooperation with Russia (and perhaps China) to show that the programs will not pose a threat. Under these circumstances, which the Clinton administration is trying to foster, Russia and China may not react by building more warheads or scuttling cooperation on other issues. However, cooperative relations with Russia are fragile and tensions with China are mounting. Therefore, TMD programs that appear benign in an atmosphere of cooperation may appear threatening if relations sour.

DEAN WILKENING
Center for International Security
and Arms Control
Stanford University
Stanford, Calif.

LIVING LARGE

In discussing how the recent Hale-Bopp comet helped break down interpersonal barriers ("Message from the Comet," *First Line, TR July 1997*), senior editor Laura van Dam offered more truth, insight, and wisdom than any scholarly paper about our tendency to become trapped in our everyday environments. She has created a manifesto that should be required daily reading for those of us for whom our laboratory, office, or computer has become our significant other.

J.A. FOULTZ
San Diego, Calif.

AN IMMEDIATE QUESTION

Showing a zipper opening a galaxy to a void that proclaims "What We Don't Know: The Unanswered Questions of Science," the cover of the July 1997 issue reminded me of a famous quote by Dorothy Parker: "There are two things I will never understand. One is how a zipper works. The other is the precise function of Bernard Baruch." The unanswered question of science? None of us knows how a zipper works!

JAMES BENENSON, JR.
New York, N.Y.

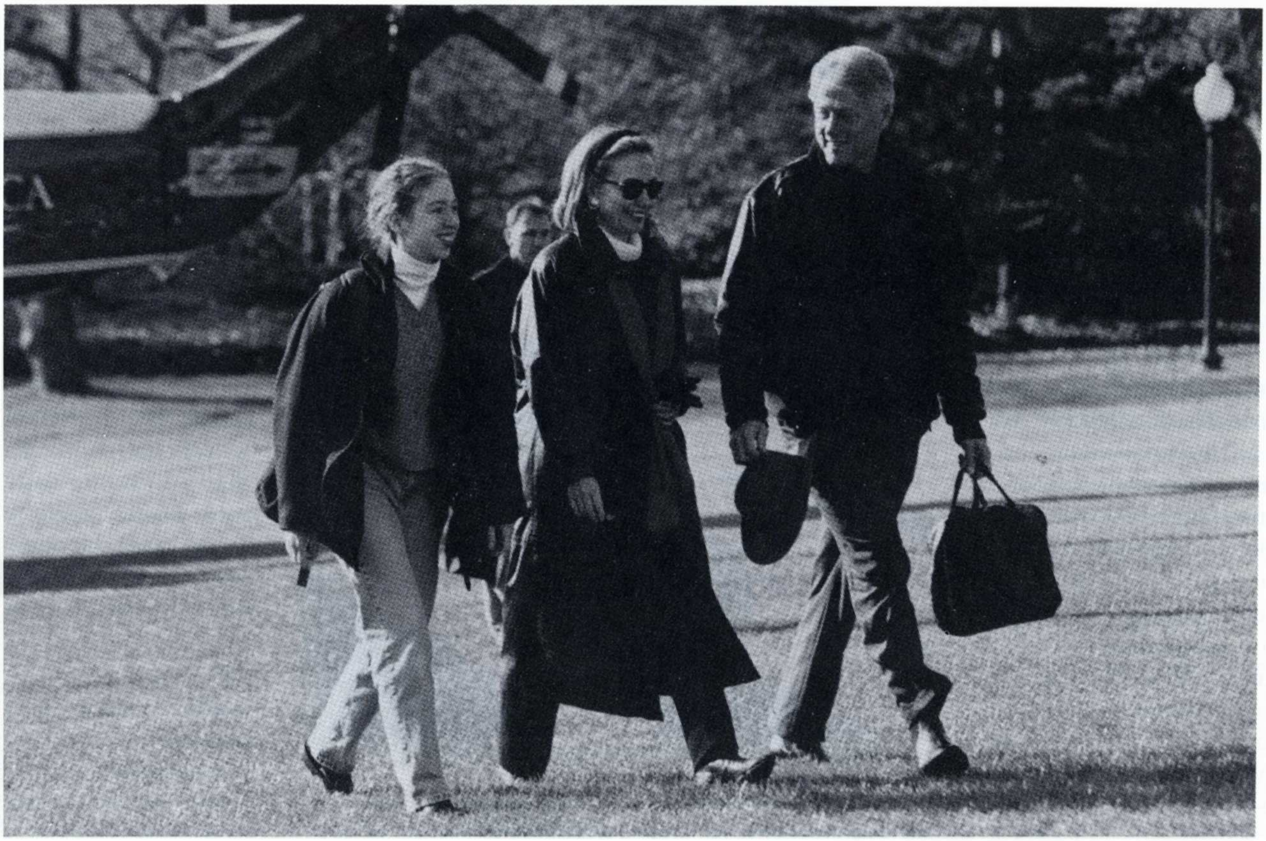
Editor's note:
Bernard M. Baruch was a Wall Street financier who served as an advisor to Presidents Wilson, Harding, Coolidge, Hoover, and Roosevelt.

A TALL TALE?

The effrontery of Paul R. and Anne H. Ehrlich in "Ehrlichs' Fables" (*TR January 1997*) takes my breath away. For more than 25 years, the Ehrlichs have been wrong in every prediction they have made about the future of natural resources ("What will we do when the pumps run dry?"), the environment ("Lake Erie is dead"), and mortality (millions of famine deaths). Documentation that the Ehrlichs and their fellow doomsayers have been wrong in their dire predictions may be found in many books, including those by Dixy Lee Ray and Lou Gusso, Ron Bailey, and me. (The Ehrlichs assail the works by these authors in their book *Betrayal of Science and Reason*.)

One would think that the Ehrlichs would ease away as quietly as possible. Instead, they declare victory and continue to press forward. Rather than apologizing, they accuse those who disagree with them, and who have been right where they have been wrong, of dire crimes against science and decency.

Continued on page 62



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FLYING SMALL

It's a Fly! It's a Bug! It's a Microplane!

Almost all of us have wished at one time or another to be a fly on the wall—but nobody wants to get swatted. A safer option might be to command a fleet of intelligent flies that could seek out and report critical information while we stay safely removed from danger. With that idea in mind, engineers at MIT's Lincoln Laboratory are now developing a micro air vehicle—a semi-autonomous spy plane small enough to hold in the palm of your hand.

Engineers at Lincoln Laboratory are developing a prototype micro air vehicle—a two-ounce spy plane less than six inches long and equipped with a sensor-bearing "cockpit," shown at the front of the plane in this preliminary model.

The idea of producing the world's first miniature intelligence-gathering plane was proposed three years ago at Lincoln Lab, where researchers sought a way to provide direct access to reconnaissance data for soldiers serving in small military units, such as those deployed in urban settings. They envisioned a portable surveillance system that could quickly inform soldiers of imminent, unseen dangers. In urban areas, for instance, such a system could enable soldiers to "see over the hill and around the corner," says William R. Davis, who manages the Lincoln Lab micro-air-vehicle program. Advanced versions might sniff out nuclear, biological, and chemical weapons in hostile terrain, assess battle damage, or monitor hostage crises or Waco-style standoffs.

> "By and large, this is going to be a flying chip."

Based largely on concepts outlined at Lincoln Lab, the Defense Advanced Research Projects Agency (DARPA) launched a $35 million program this year to develop prototype micro air vehicles, soliciting preliminary proposals from industry and academia. Organizations competing for funding include university laboratories such as Georgia Tech Research Institute (GTRI), aerospace companies, and small businesses.

At the same time, DARPA has provided initial funding to Lincoln Lab to develop a fully functioning prototype, which researchers expect to complete within three years. Weighing two ounces and measuring less than six inches in length and width, the prototype vehicle will fly at 20 to 30 miles per hour, operate within a radius of up to 3 miles (the limit relates to the expected range of the vehicle's communication system), and remain airborne for up to an hour. It must also have reconnaissance and navigational capabilities.

"By and large," says Milan Vilajenik, who heads Lincoln Lab's Engineering Division, "this is going to be a flying chip."

Given its tight size and weight constraints, getting this flying chip off the ground and keeping it there will be no mean feat. "As you go down in size," Vilajenik explains, "existing technology is too big. Most of the subsystems will have to be developed."

The first challenge is to create an efficient wing design that can provide enough lift and low enough drag for a vehicle in this size range, in which aerodynamic behavior differs from that of larger, faster aircraft. The Lincoln Lab team calculated that a hovering craft with rotor blades would require about twice the power of a fixed-wing vehicle. To minimize power requirements, therefore, the team is evaluating several fixed-wing configurations using propellers for propulsion, says program manager Davis.

But Robert J. Englar, a principal research engineer at Georgia Tech, argues that even with a propeller, a conventional wing will not generate enough lift to keep a very small, slow vehicle moving through the disruptive airflow that it will likely encounter. Georgia Tech has submitted a proposal that Englar declines to discuss, but Sam Blankenship, coordinator of GTRI's Microflyer Program, says that engineers may ultimately need to look to the flapping wings of small birds and insects as models for energy-efficient flight.

A strong propulsion system can compensate for shortcomings in aerodynamic performance, notes Davis, but more powerful propulsion units are likely to weigh more—and designers want to reserve weight for data-collecting sensors and communication systems. The Lincoln Lab team determined that at the small scale required, jet engines would consume too much fuel, while power

PHOTO: MIT LINCOLN LABORATORY

sources such as batteries would weigh too much and provide too little power. Lincoln Lab engineers identified internal-combustion engines and fuel cells as the most promising near-term alternatives and hope to create miniaturized versions of internal-combustion engines within one to two years.

Along with a robust propulsion system, the diminutive vehicle needs a flight-control system so that it can maintain its course in the face of air turbulence or sudden gusts of wind. Because the plane will travel out of the troops' sight and may encounter rapidly changing flight conditions, "a soldier can't fly the vehicle like a model airplane," says Davis. His team determined that to execute maneuvers, the prototype could rely on small-scale devices—sensors that measure aircraft speed, acceleration, and atmospheric pressure, and electrical actuators that move the plane's aerodynamic surfaces.

Davis points out that sophisticated microfabrication techniques make it possible to manufacture sensors and actuators with low power requirements on a very small scale. As microplane development matures, however, designers expect to replace these tiny devices, which use moving parts and must be mounted separately, with micro-electromechanical systems—high-precision systems that resemble computer chips and are produced using methods similar to microcircuit fabrication. These could be embedded in a microplane's wing, saving precious weight and providing more efficient control.

Finally, Lincoln researchers plan to develop a very small imaging system for the vehicle and a portable ground station—a laptop computer and a small parabolic communications dish—to transmit photos. They envision a two-gram, one-cubic-centimeter visible-light camera positioned beneath the plane and obtaining million-pixel images—pictures sharp enough to identify military vehicles and personnel from a 100-meter altitude. The challenge in developing the imaging system is not to design or manufacture individual components but to integrate them without exceeding tight mass and power constraints.

Indeed, integrating this tightly packed assortment of reconnaissance, propulsion, flight control, and other subsystems will be the final hurdle, Vilajenik notes. For example, designers may have to isolate a vibrating, heat-producing internal combustion engine from an imaging system sensitive to those disturbances, and prevent electromagnetic interference between electric motors and the communications antenna.

As engineers develop ways of squeezing more functions into smaller packages over the next decade or two, they expect that payload capacity, endurance, and range will rise. The Lincoln Lab team envisions advanced micro air vehicles that perform tasks as diverse as detecting chemical signatures of unconventional weapons, deploying stationary sensors to monitor unpatrolled areas, and imaging and recording the sounds of scenes in and around buildings.

—*Mark Dwortzan*

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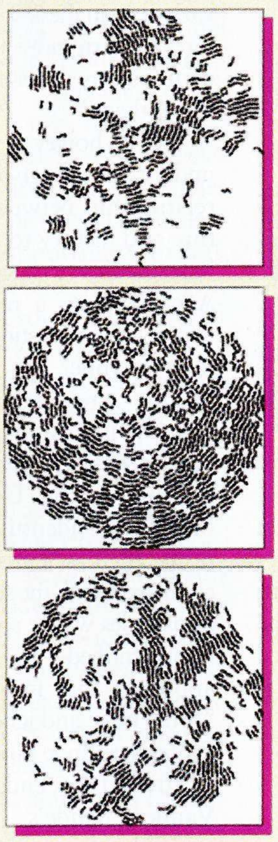
CLEAN AIR

Tracking Sootprints

Was a coal miner's lung cancer triggered by coal dust or cigarette smoke? Which is more to blame for a city's poor air quality: diesel buses in the streets or gas-fired turbines at a nearby electric power plant? And how should government target air-pollution-control efforts to best protect human health? The answers to all these questions, John Vander Sande believes, lie in the structure of individual particles of soot.

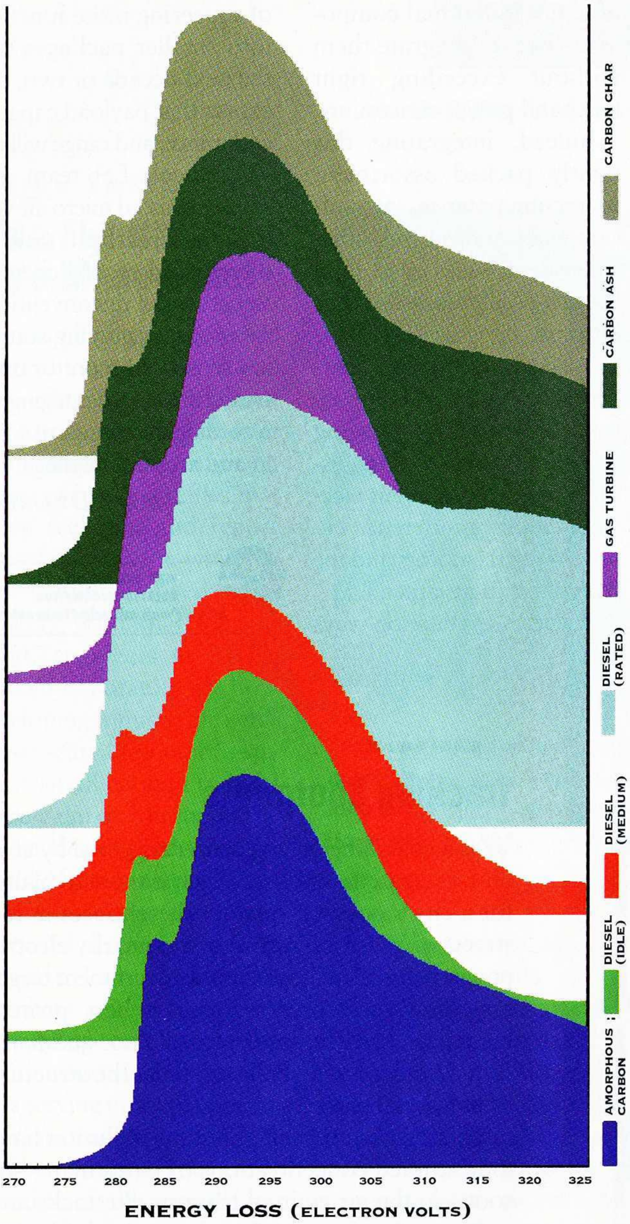
Scientists concerned about air pollution have long studied concentrations of particulate—or soot—in the air emitted from smokestacks and tailpipes. Some researchers have also looked at the chemical composition of those emissions. But a team of researchers led by Vander Sande, a professor of materials science and engineering at MIT, is the first to mine the wealth of information found in each tiny chunk of impure carbon.

What makes this forensic feat technically possible, Vander Sande explains, is his team's discovery that each soot particle has a unique internal structure—a complex, partially ordered lattice of carbon atoms he dubs a "sootprint." Particles from different sources may also contain traces of different metals or clump together in different shapes—for instance, those discharged by a diesel engine look significantly different from those



These computer-enhanced electron micrographs show "sootprints" of particles that are generated by the same diesel engine operating at different speeds.

ILLUSTRATION: ARPAD PALOTAS



Scientists can distinguish soot particles from different sources by comparing patterns generated by a technique called electron energy loss spectroscopy. Each curve shows how electrons lose energy as they encounter a soot particle from a particular source.

spewed from a smokestack. In fact, Vander Sande says his group has been able to discern differences in the sootprints that are produced by a diesel engine when it is idling versus when it is revving.

Soot Sources

Vander Sande estimates that about 20 major sources produce soot, including oil- or coal-fired power plants, industrial gas turbines, diesel engines, cooking stoves, and wood-burning processes. While soot particles from the same type of source may vary somewhat, the team's goal is "to differentiate among these broad categories of airborne particulate accurately enough so that we can reliably assign [soot specimens] to specific sources."

Vander Sande says a particle's sootprint reflects its so-called thermal history: the temperature at which it burned, the amount of oxidation at the time it was formed, and the type of fuel it derives from. "Ultimately," Vander Sande says, "we hope to be able to use our growing understanding of the variations in these soot signatures to learn more about the combustion process that forms them."

"So far, however, we don't understand enough about the relationship between structure and history to begin to have predictive power," says Adel Sarofim, a renowned expert on combustion. A former member of Vander Sande's research team, Sarofim is now a research professor of chemical engineering at the University of Utah. To identify a sootprint, then, scientists must compare it with the sootprints of particles whose source has been identified—an empirical approach that is based on "brute force and ignorance," as Vander Sande puts it.

Toward that end, Vander Sande's research group has begun to amass a library of soot particles. The project began in 1993, with a grant from the U.S. Bureau of Mines, and has subsequently received funding from the Environmental Protection Agency. Vander Sande and his colleagues have painstakingly analyzed the structure and composition of soot specimens from five different types of combustion, with four to six variants in each category. Their goal is to analyze at least 10 variants of all 20 major types of soot. The resulting images will provide a database that will allow scientists to match unidentified soot particles with the most likely source.

Vander Sande's research group has begun to amass a library of soot particles.

A Battery of Tests

Members of Vander Sande's team employ a battery of tests to obtain a full picture of a given soot particle. First, they analyze the specimen under a high-resolution electron microscope, which reveals a mosaic of grains similar to the pattern of bumps on the skin of an orange. Computer enhancement techniques then transform the image into a mazelike series of lines that actually resembles a fingerprint. Using pattern recognition technologies similar to those employed by law enforcement officials to match fingerprints, scientists can determine how closely these different kinds of

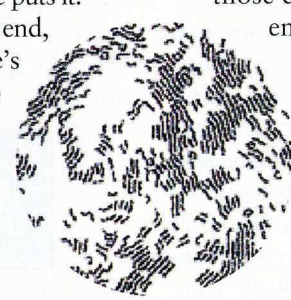
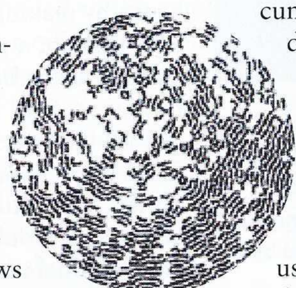


DIAGRAM: DAVID C. BELL

soot structures resemble one another.

A technique called energy-dispersive x-ray analysis provides additional clues to the soot's origins. Researchers use a special device to shoot electrons at the particulate samples and image the x-ray spectra that result. Because different types of atoms, such as iron or zinc, generate distinct patterns of x-rays, the technique helps scientists identify the many trace metals and other infinitesimal—and potentially toxic—elements imbedded in the carbon structure.



Quickly, Vander Sande ticks off three more tests in his laboratory's arsenal. One, electron energy loss spectroscopy, allows researchers to graph a curve showing the rate at which electrons lose energy as they encounter a soot sample. The test yields slightly different curves for different types of soot. Lab team members also conduct precise size measurements because the particles' sizes vary according to the type of combustion. And the team images groups of soot particles as well as individual particles to observe the way they aggregate into clumps. As Vander Sande explains, particles generated by wood burning tend to form "necklaces" while those from a coal-fired plant are likely to resemble "a grape cluster."

This forensic tool kit gives scientists "enough sensible, meaningful metrics not only to differentiate among kinds of particles but to pinpoint their source with a great degree of confidence," according to Vander Sande.

Right now, the major obstacle to progress is the labor involved in imaging each individual particle. Tests must be done essentially by hand.

Because the tests are so painstaking and costly, Vander Sande points out, automating the imaging techniques is essential if sootprinting is to become widely available. If the process can be made less cumbersome, Vander Sande hopes to create a hybrid instrument that state or regional environmental agencies could use to test and analyze soot particles on behalf of private parties or state or federal officials.

The opportunity to link air emissions to different types of sources has caught the attention of many environmentalists. Steven Dujack, a spokesperson for the Environmental Law Institute, based in Washington, D.C., suggests that people suffering from pollution-related health problems could use sootprints to support class-action suits against polluters whose emissions exceed legal limits. Neighbors might use the new evidence to force tighter emission standards for airports or power plants. "More legal cases might be brought," Vander Sande concurs, "but frivolous lawsuits will also be more easily dismissed."

—*Seth Shulman*

Trends

INNOVATIONS FROM THE WORLD OF TECHNOLOGY

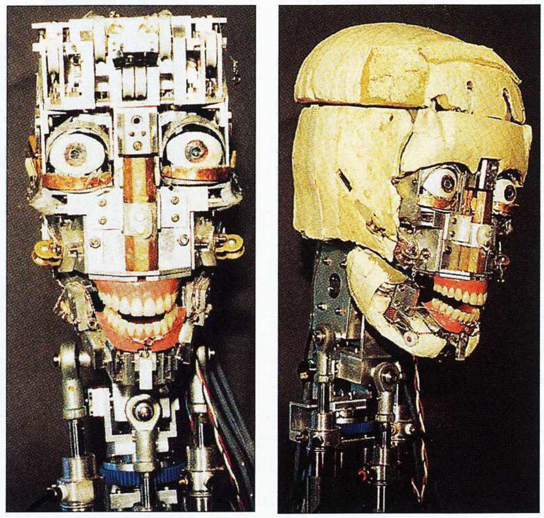
ROBOTICS

How to Make a Robot Smile

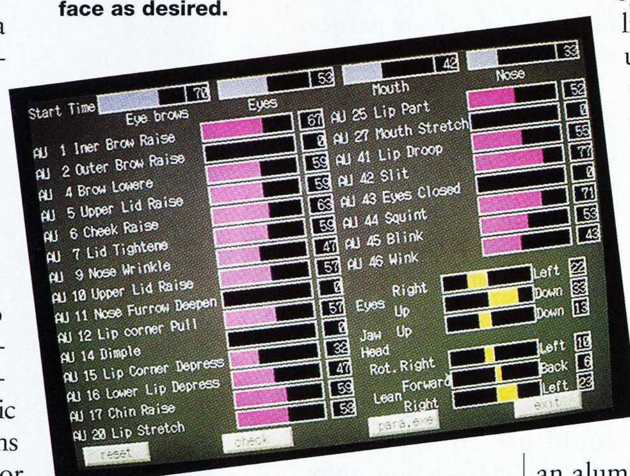
In a completely new wrinkle on the old adage, "Smile and the world smiles with you, frown and you frown alone," Japanese researchers are producing a generation of robots that can identify human facial expressions and then respond to them. A team lead by Fumio Hara, a mechanical engineering professor at the Science University of Tokyo, has built a female robotic head that can both recognize and express fear, happiness, surprise, sadness, anger, and disgust.

The main goal of Hara's project, which is supported by a five-year, $3 million grant from the Japanese government, is not merely to produce a robotic version of monkey-see, monkey-do. Instead, the aim is to create robots that will "empathize" with us and make us feel more comfortable as they read emotional changes expressed in our faces. The researchers expect that such visually emotive robots would be appreciated by factory workers forced to share the line with electronic workmates. The robots may even be useful as teaching aids for certain autistic children who have a communications disorder that makes it difficult for them to understand facial expressions and respond to them correctly.

One surprising feature of Hara's research is its genesis. During the great economic expansion in Japan in the 1970s, accidents began to occur in newly constructed chemical plants. Hara surmised that plant operators were having difficulty spotting problems by reading banks of digital readout panels. "I thought what they needed was a more global view of what was going on in the plant," he says, "and if something went wrong, it might be expressed, for example, as a sad face."



An "emotive" robot that reads human expressions and responds in kind (next page) was constructed from an aluminum head fitted with false teeth, eyeballs, rubber mask, wig, and tiny gears that can be controlled by a computer program (below) to contort its face as desired.



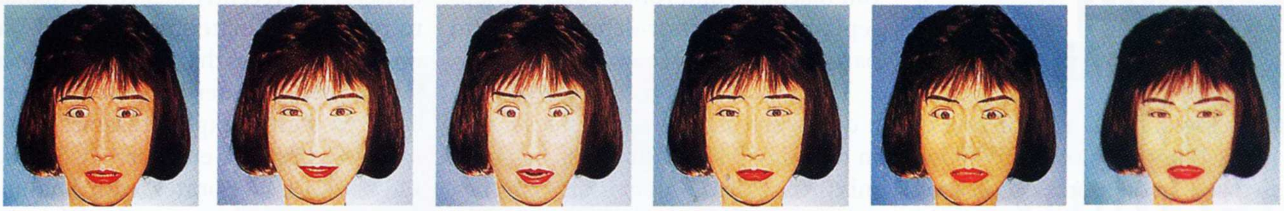
Alas, the engineers soon confronted major hurdles. They found that it was not only difficult to assign facial expressions to the wide range of operational wrongs—from a messy plant floor to dangerous changes in temperature or pressure in the manufacturing process—but also that individual human operators interpreted the same expressions in different ways. The task of tying facial expressions to plant conditions eventually proved so complex that Hara gave up on the research.

But in the mid-1980s, when one of his students expressed interest in robotic research, Hara wondered if the facial-expression approach, although a failure on a plant level, might work between individual robots and humans. He began by making use of work by Paul Ekman, a professor of psychology at the University of California at San Francisco, who divided the movements of human facial expressions into 44 categories, or "action units." Each action unit would correspond to an individual movement, such as eyebrows going up or down or lips pursing. Combining action units in various ways produced different expressions. For example, disgust entails lowering the brow, wrinkling the nose, and raising the chin.

Beginning in the 1990s, Hara's group set about creating six expressions—fear, happiness, surprise, sadness, anger, and disgust—which, according to Ekman, are universal to all human cultures. The team constructed an aluminum robot head with 18 air-pressure-driven microactuators—in essence, tiny gears—that could mimic 26 facial movements. The next step was to cast a face in silicone rubber from a mold taken from one of the male students in the laboratory. Because the all-male group desired a female presence in the lab, they feminized the male face by adding a natural hair wig, rouged cheeks, and lipstick. The head was also fitted with false teeth.

Through trial and error, the re-

PHOTOS: FUMIO HARA



FEAR HAPPINESS SURPRISE SADNESS ANGER DISGUST

searchers hooked up tiny wires from the actuators to spots on the mask that, when moved, would recreate the action units required to reproduce the desired six expressions. The robot's head and eyeballs were also engineered to make humanlike movements. Finally, the Japanese engineers put a tiny camera in the robot's left eye to scan a human face when positioned about one meter away. A computer connected to the camera determined the person's expression by searching for brightness variations in different areas of the face.

The computer observed changes in the dark areas—the eyes, mouth, nose, and eyebrows—that occur when a face moves from its neutral, emotionless expression to that showing one of six emotions. Using a neural-network-based self-training program, the computer was eventually able to recognize within 60 milliseconds how changes in the brightness patterns of an individual's face related to the expressions of a given feeling. Such processing speed combined with refinements in the design of the actuators enabled the robot's silicone face to respond to changes in expression with humanlike speed.

The robot was surprisingly accurate, correctly guessing the expressions of test subjects, on average, 85 percent of the time. It also fared equally well as a facial actor. In fact, a group of students correctly identified the robot's expressions 83 percent of the time. By comparison, the same students identified the facial expressions of professional actors 87 percent of the time.

Since accounts of the robot's performance first appeared in the early 1990s, Hara has been approached by some unexpected parties. These included an artist interested in creating what he believes is a new art form—humans and robots reacting to each other's expressions—and several psychologists in Japan who think such a robot could help certain handicapped children overcome difficulty manifesting appropriate expressions. The psychologists would have the robot act as a kind of two-way prompt, for example, demonstrating what a happy smile looks like and, after assuming a neutral expression, indicating when the child has smiled by smiling back.

More immediately, Hara's team is working on a "mouth robot" whose actuators would realistically mimic lip movements during speech. Such a robot might help people with speech or language disabilities, Hara says, because studies show that more than 50 percent of speech understanding stems from facial expression and movements.

—Stephen Strauss

Smarter Cancer-Killing Drugs

For decades, soldiers on the cancer front have dreamed of therapeutic agents that work like hired assassins—homing in on tumor cells and killing them without laying waste to innocent bystanders. Now there is hope that drugs combining aspects of both chemotherapy and radiation can treat certain cancers in just that way.

One team of researchers explpring this approach, led by David Scheinberg, chief of leukemia services at Memorial Sloan-Kettering Cancer Center in New York, is testing such a drug on 20 leukemia patients who failed to respond to conventional chemotherapy. The drug consists of atoms of the radioactive isotope bismuth-213 attached to antibodies. Those, in turn, bind to a protein found on the surface of leukemia cells. When the bismuth-213 decays, it releases alpha-particle radiation that destroys the target cells.

Several hurdles had to be overcome during the 15 years required to develop the strategy. "First we had to find a suitable antibody that generated a minimal immune response," Scheinberg says. The solution came in the form of a monoclonal antibody dubbed Smart M195, designed by computer at Protein Design Labs of Mountain View, Calif. A second obstacle was figuring out a way to attach the cancer-killing agent to the antibody. "You don't want the radioactive atoms to fall off and end up someplace else like the liver where they can cause real damage," Scheinberg adds. The developers met this challenge by employing a so-called "linker" molecule, called DTPA, that chemically binds the radioisotope to the antibody.

In the first clinical trial, the drug reached its target within five to ten minutes after being injected in patients. And the drug seems highly selective, delivering 30,000 to 50,000 times more radiation to leukemia cells than to healthy tissue, Scheinberg says. The potency and precision of killing is amazing, he adds. "It appears that a single bismuth atom can kill a cancer cell, which would make it the most potent agent I'm aware of."

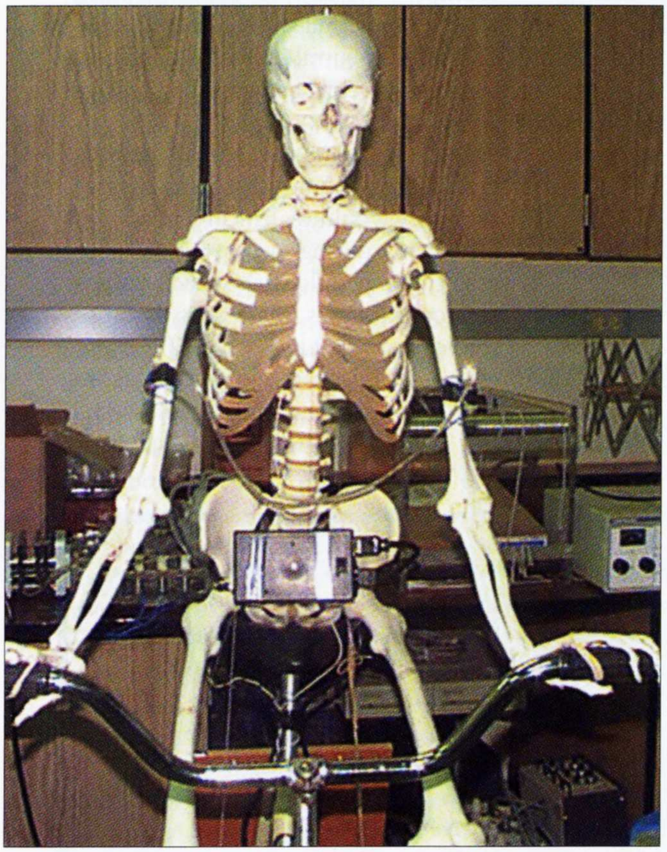
Trials have shown no evidence of acute toxicity or other major side effects caused by inadvertent damage to healthy cells. "If we can demonstrate significant [anti-cancer] activity without significant toxicity," Scheinberg says, "we'll select appropriate doses and try this out on a larger number of patients."

—STEVE NADIS

BIOMATERIALS

We Can Rebuild You

The room looks like a set for one of those grade-B horror movies Ed Wood loved to make. In one corner, a skeleton draped in wires spasmodically jerks its arm up and down—meet "Mr. Bony." In another corner, strange, gelatinous creatures undulate like jellyfish inside tanks. More of the slippery blobs wiggle inside Tupperware containers that overrun the cabinets. "On campus, they call this the 'spooky lab,'" notes Mohsen Shahinpoor, director of the University of New Mexico's Intelligent Materials Laboratory. "And to tell you the truth, it can get a little scary around here."



Mr. Bony rides again: A team at the University of New Mexico's Intelligent Materials Laboratory has created synthetic muscles from polymer gels that can flex and relax when stimulated by an electric current. An artificial human skeleton outfitted with the gel material is able to power an exercycle.

Shahinpoor, the genial assistant dean of the College of Engineering, is an unlikely successor to Dr. Frankenstein. Although he is not trying to create life in his laboratory, the inanimate materials he melds together squirm and writhe like living entities. His true objective is to develop a host of supple artificial muscles that may eventually run machines and robots, and perhaps replace worn-out or defective human parts.

This tantalizing prospect stems from a discovery made by Israeli scientists in the late 1940s: certain plastic-liquid mixtures called polymer gels can flex and relax like natural muscles. The slimy fiber bundles shrink when the solution they're immersed in becomes acidic; but stir in some base and they swell to many times their former size.

The same effect can be induced by attaching electrodes to the material and passing a current through it. This works because of electrical attraction and repulsion: when polymer gels are in an acid solution, negative ions from the gel are attracted to positive ions from the acid that permeate the gel, causing the material to contract. The opposite phenomenon occurs in an alkaline solution: the material expands when its negative ions are repulsed by negative ions that have infiltrated from the solution.

Some 50 years after this conceptual breakthrough, research on artificial muscles has recently picked up thanks to progress in materials science. "We now have theories that tell us in advance how to design materials with the properties we want," explains Daniel Segalman, a chemical engineer at Sandia Labs who collaborates with Shahinpoor. "This eliminates much of the trial and error."

Working with artificial silk fibers and a blend of polyvinyl alcohol, polyacrylic acid, and other compounds, Shahinpoor and his Sandia colleagues have fabricated simple devices that demonstrate possible uses for synthetic muscles. For instance, they have designed small motors that harness the expansion and contraction of a polymer gel to open and close a valve, compress a spring, or rotate a pulley.

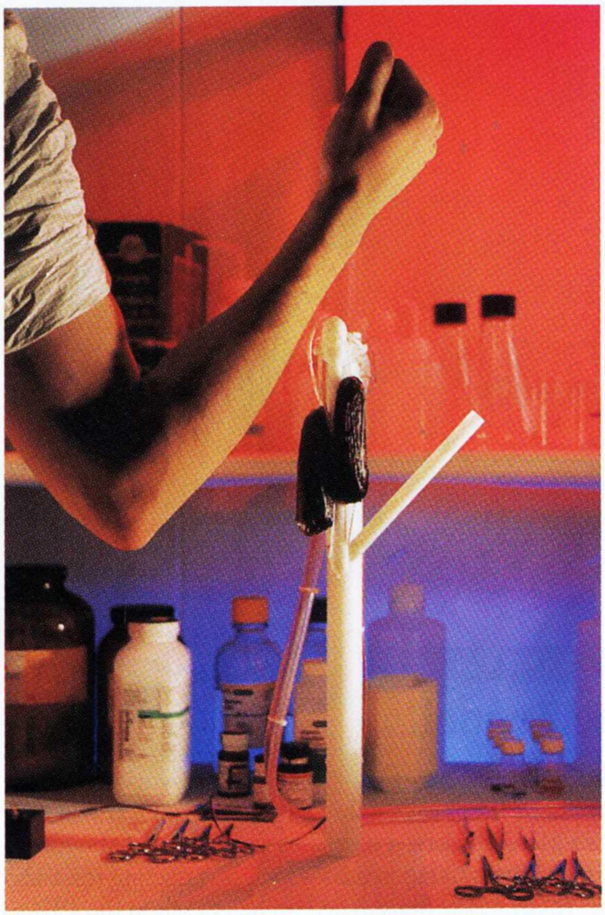
Shahinpoor (a.k.a. "Mo the Muscle Man") is already exploring more ambitious ideas. The U.S. Navy, for instance, is interested in his swimming "robofish," which moves by flapping its tail without relying on any mechanical parts. The Navy's motivation is to devise a noiseless propulsion mechanism for submarines.

The Army, meanwhile, recently gave Shahinpoor a three-year contract to develop exoskeletal systems that could enhance human muscles, providing extra strength for tired soldiers. As part of that just-completed work, Shahinpoor and his colleagues attached some muscles to a jacket sleeve to supply added flexing power. A potential drawback of exoskeletal clothing or suits, according to Sandia engineer Walter Witkowski, is that "the weight can offset the extra strength it might render."

That problem, however, could be avoided in the weightless environment of space. In fact, Shahinpoor suggests putting muscles in space suits to give astronauts more strength and dexterity in their legs, arms, and hands, and NASA is supporting his efforts. "In current space suits, you can't close your hands easily, or bend your elbows or knees, because the pressure in the suit makes it so difficult," he says. "We're hoping that people will be able to move more freely with augmented power."

Shahinpoor would also like to over-

PHOTO: ARTIFICIAL MUSCLES RESEARCH INSTITUTE/ UNIVERSITY OF NEW MEXICO



Researchers at MIT's Artificial Muscle Project have incorporated force and position sensors into synthetic muscles on a robotic arm, enabling more precise motion control.

haul robots by exchanging clunky gears, motors, and pulleys for flexible, electronically controlled muscles. Mr. Bony, who can move his arm with a set of artificial biceps and triceps, is an admittedly primitive step toward the development of humanlike "bionic" robots.

Team members are also exploring several medical applications. They're working, for example, with medical researchers at Columbia University and the University of New Mexico to study the idea of wrapping diseased hearts with artificial muscles that would keep them beating regularly in lieu of a transplant operation. The University of New Mexico has already filed patent applications for the idea, which will first be tested on animals, possibly rabbits. But it is still too early to apply for approval from the Food and Drug Administration, Shahinpoor says. Meanwhile, companies are considering the use of polymers as artificial sphincters to treat incontinence. The possibility of using artificial muscles for muscle repair or perhaps even "bionic" limbs lies further down the road.

David Brock, who heads the Artificial Muscle Project in MIT's Artificial Intelligence Laboratory, is also pursuing several applications for polymer gels. Indeed, his lab, like its New Mexico counterpart, is inhabited by a host of muscle-driven machines—including an imitation fish that resembles a floating wig and a movable joint reminiscent of Mr. Bony's arm. Brock cautions that many advances will be needed before any but the simplest applications become practical. Implants are especially problematic, he says, as one has to worry about biocompatibility, toxicity, and rejection when placing foreign materials inside the human body. The good news, however, is that many artificial muscles may already be composed of biocompatible materials, Brock notes,

PHOTO: DAVID BROCK

and, if not, they could likely be encapsulated in more benign substances that do not trigger an immune response.

For now, Brock is focusing on more immediate concerns, explaining that "once we come up with great polymer gels and great ways to activate them, the applications will come easily." Brock and Woojin Lee, an engineer formerly working in his lab, have recently demonstrated a mechanical control system that can precisely regulate the motion of an artificial muscle, as well as the force it exerts. The polymer gels swell and contract in response to chemical stimuli the same way Shahinpoor's materials do, but the artificial muscle has been incorporated into a mechanical apparatus attached to a robotic "arm" and equipped with force and position sensors that allow an unprecedented degree of motion control. "You can tell it where to go, and it goes there," Brock says.

Mohsen Shahinpoor is now developing exoskeletal muscles for military jackets and spacesuits that could give soldiers and astronauts greater strength in their hands, arms, and legs.

Of course, if we ultimately use such artificial muscles and devices to power a new generation of robots and to reengineer humans, we will then have something new to think about: As robots become more like us, will we become more like them?

—*Steve Nadis*

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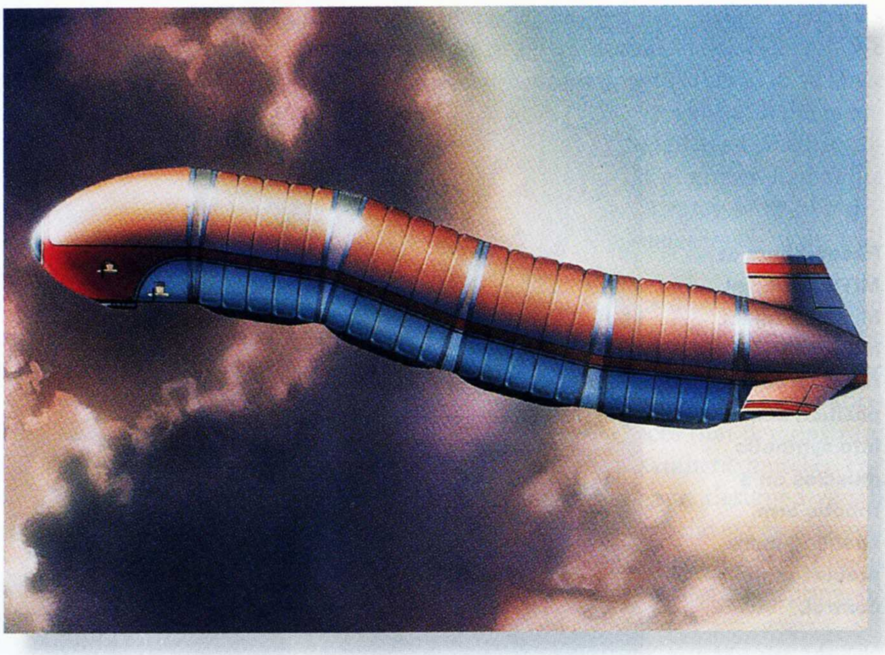


TRANSPORTATION

The Zeppelin Also Rises

When forest fires broke out in a remote area of Massachusetts a couple of years ago, firefighters hampered by a lack of access roads to the blaze relied on helicopters to douse the flames. But the helicopters were ill-equipped for the task: each small craft could carry only 100 gallons of water. In fact, to extinguish the blaze, firefighters spent several days scooping water from a pond, flying to affected areas, dumping water on the flames, and then returning for more pond water.

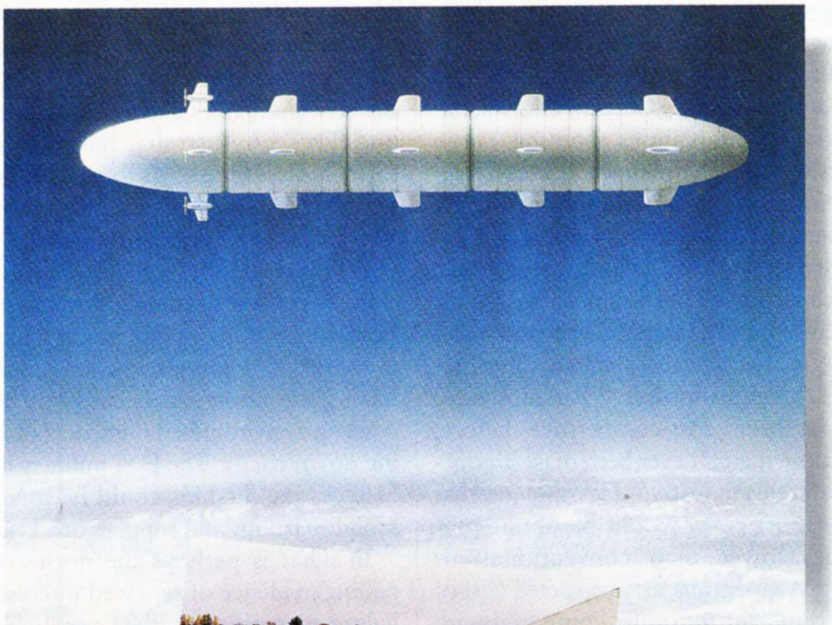
Mike deGyurky, a program manager at the Jet Propulsion Laboratory (JPL) in Pasadena, Calif., figures there must be a better way to handle such emergencies. His novel approach would entail deploying a giant blimp, perhaps a mile in length. With a capacity of 50,000 tons or more, such an airship could pour more than 10 million gallons of water on a forest fire. It could also be used to transport food and water (perhaps even a small iceberg) to drought-stricken regions, dump tons of dirt and sand on a nuclear reactor to smother an incipient meltdown, or even deploy a vast tarp to contain oil spills from leaky seafaring tankers.

The concept began as a "what-if" exercise spawned during one of JPL's lunchtime brainstorming sessions. DeGyurky was also inspired by Theodore von Karman, JPL's cofounder who speculated about mile-long blimps after conducting research on lighter-than-air vessels in the 1930s.

"We're basically taking von Karman's idea and applying technologies that have become available in the intervening 60 years," deGyurky explains. "These include lightweight materials—synthetic fibers such as Kevlar, graphite epoxies, and the like—that are awesome in strength, and thin-film solar cells that would line the roof of the airship and provide most of the propulsive power."

DeGyurky's idea is still in the conceptual stage, and it's unclear whether the plan will ever reach fruition. Nevertheless, interest in developing airships for a variety of transportation needs is rising again, 60 years after the Hindenburg explosion in 1937 grounded the commercial industry. For example, Lloyd Van Warren, deGyurky's former colleague at JPL who now heads his own engineering firm, Warren Design Vision in Little Rock, Ark., has a somewhat different notion. Instead of a single gigantic ship, Warren is pursuing a "train in the sky"—a string of blimps

PHOTO LEFT: ARTIFICIAL MUSCLES RESEARCH INSTITUTE/ UNIVERSITY OF NEW MEXICO



Mile-long blimps (left and top) that can carry more weight at lower cost "than anything that flies," according to designers, are still on the drawing board, but scale-model prototype units (directly above) have already taken flight.

linked together like sausages.

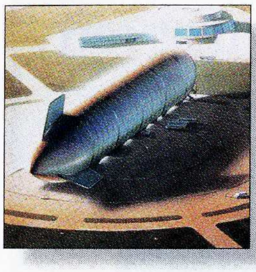
This "skytrain" would offer several advantages, according to Warren. "Flying in formation would reduce aerodynamic drag," he says. "With a train of 50 airships, as opposed to 50 independent airships, you could realize perhaps a 50 percent savings in energy, and the savings go up as the speed of travel increases. That's why ducks fly in formations, bicyclists ride in packs, and trucks travel in convoys." Flexibility is another advantage: a train flying from Seattle to San Diego could uncouple along the way, dropping cars in Portland, San Francisco, and Los Angeles, and thus enable passengers and goods to travel nonstop. Security is an added bonus: whereas the failure of a gigantic blimp would mean great financial loss for its owner, one car in a string could go down without jeopardizing the entire train. Finally, solar-powered propulsion would operate virtually pollution-free.

Warren has analyzed "sky boxcars" of varying sizes—everything from a 46-foot-long ship costing about $300,000 to a half-mile-long $9 billion unit. Although preliminary price estimates are daunting, he predicts that costs could come down considerably as the price of solar cells, by far the most expensive element, continues to drop. That would raise the economic viability of skytrains and the prospects that the idea will ever proceed beyond the computer modeling stage.

The skytrain is not the only grandiose proposal being floated these days. Charles Owen, a professor of design at the Illinois Institute of Technology, and his students won the Bronze Prize at the 1993 International Design Competition in Osaka, Japan, for their conception of the AeroCarrier, a mile-and-a-half-long airship that would be "like a city in the sky," according to Owen. The egg-shaped structure, designed to be longer than the Sears Tower is tall, would carry 3,500 passengers and crew members and still haul 35,000 tons of cargo—more than four

ILLUSTRATIONS AND PHOTO BY PAN ATLANTIC AEROSPACE CORP.

times the capacity of the largest seafaring container ships. Once filled with helium gas, the AeroCarrier would stay aloft indefinitely. Loading and unloading of passengers and cargo would be handled by six smaller vehicles called shuttle pods.



Compared with seafaring container ships, mammoth airships could deliver four times the payload at four times the speed to virtually any destination on earth.

Owen concedes the odds are slim that an airship on the mammoth scale he proposes would ever be built. But the idea has generated inquiries from several businesses, he says, including a company in Iowa interested in using an airship to transport grain, and a Texas firm that would deliver heavy oil-drilling equipment to Siberia. The attraction, says Owens, is the ability to move "very big things" not feasible by standard air freight.

Fredrick Ferguson, head of the Pan Atlantic Aerospace Corp. in Ottawa, has also received inquiries about his Cargo Airships, which are much closer to realization. In fact, Pan Atlantic has already designed a 1,500-foot-long airship composed of modular, cylindrical sections. Each section would be amenable to mass production—a feature that could make the airships "cheaper than anything that flies," Ferguson says. "Airships have never been cost-competitive before, because there's never been mass production in this industry." He estimates that transport costs would be about four times lower than conventional air cargo—operating at a projected cost of 10 cents per ton-mile, compared with the 40-to-50 cents per ton-mile charged by standard air carriers. Although several times slower than cargo airplanes, the cargo airships could deliver freight three to four times faster than container ships, Ferguson maintains.

Pan Atlantic has built and flown two 50-foot prototypes and hopes to have a 600-footer up and running soon. Meanwhile prospective customers, including delivery companies like Federal Express and TNT of Australia, have already expressed interest. A tour company hopes to fly passengers from downtown Washington to a nearby (though not yet built) theme park in a Pan Atlantic airship. A Vancouver mining firm has told Ferguson that his airship might make it economical to harvest small mines that have gone untapped because of high costs and environmental impacts of laying down roads. The U.S. military also believes the airships could be used to mobilize troops and supplies quickly.

In what is perhaps the most compelling evidence of renewed interest in lighter-than-air ships, the German Zeppelin company is now back in business after lofting a 240-foot-long airship this April—its first since the 1937 crash. Called Zeppelin NT (New Technology) the airship may soon see a 360-foot-long successor that could ferry 84 passengers.
—STEVE NADIS

HARNESSING BROWNIAN MOTION

Small particles suspended in a liquid are constantly buffeted by collisions with other molecules, causing them to jiggle erratically in a manner known as Brownian motion. The phenomenon—first observed by botanist Robert Brown in 1824 and later described theoretically by Albert Einstein—is ubiquitous in nature, an inevitable consequence of thermal energy in the environment. Now, University of Chicago biochemist R. Dean Astumian claims that by applying external forces and employing various tricks, we can "bias" these otherwise random meanderings and "get things to move more one way than the other," thus laying the groundwork for potentially useful devices.

One arrangement would consist of a tilted pipe that features an array of positive and negative electrodes attached along one side and that also contains a fluid filled with negatively charged particles. When the electricity is turned on, electrical attraction will induce all the particles to accumulate at the positive electrodes. When the electricity is turned off, gravity will cause most particles to drift downhill. But owing to Brownian motion, some occasionally will go uphill. If these upward-traveling particles make it past the negative electrode, which is located just barely above the positive, they will be forced uphill to the next positive electrode when the electricity is turned back on. The rest of the particles that drifted downhill will return to the positive electrode where they were originally congregated. "By repeating this process, turning the electricity on and off at precisely the right times, we can generate net uphill motion," Astumian explains.

If bigger particles—composed of the same material and bearing the same negative charge—are added to the pipe, they will tend to move downhill more than the smaller particles, because they experience a stronger tug from gravity with comparatively less frictional drag. "If you do this right, you can end up with a situation where the big particles move downhill while the small particles move uphill," Astumian says. That could be extremely useful, he adds, because at present, "there are no really good ways of separating particles by size." The "biased Brownian motion" approach, he says, might provide the basis for practical devices that could continuously separate proteins or other molecules in biological or chemical processing.

But even if such applications don't pan out, the research should, at the very least, contribute to a new appreciation of the random, thermal-driven motion also known as thermal noise. "We've always looked at thermal noise as something to get rid of," Astumian says. "But now we're taking the opposite approach and trying to use it constructively."

—STEVE NADIS

A STUDY IN COMPLEXITY

He conducts **secret experiments** alone after hours at the software company he founded. He has the arrogance to announce that he's going **to reinvent physics**—and though he won't share his findings with anyone, his colleagues think **Stephen Wolfram** **just may be brilliant enough to do it.**

BY ROBERT LEE HOTZ

In the bright sunshine filtering through Caltech's blooming jacaranda trees, there is little to distinguish the plump, middle-aged physicist from the knot of faculty and students outside the university auditorium, save the tiny StarTac cellular phone clipped to his baggy black trousers, his laptop computer—the thinnest money can buy—and the attentive publicist who carries it for him.

Working up his nerve, a 17-year-old Caltech physics major edges up to the man and asks him to autograph a set of computer disks. The physicist is Stephen Wolfram. The disks contain a computer program he designed called Mathematica, the centerpiece of the $100 million company he founded after leaving academia in 1986.

As Wolfram scribbles his signature with a modest flourish, he seems to savor a moment of perfect personal equilibrium, such as a tightrope artist might enjoy after a back flip on the high wire, kept aloft solely by his faith in himself. Indeed, many consider Wolfram one of the most intriguing high-wire acts in physics today.

Working without a net—the security of an academic position or the collaboration of colleagues—Wolfram is using the pattern-generating capacities of computers to try to uncover fundamental rules underlying the extraordinary, chaotic complexity of the universe. In doing so, he says, he is rebuilding physics from the bottom up by developing techniques that rival the mathematical equations conventional physicists use to describe and predict events in the world around us.

To physicists, mathematics is a language. It offers a vocabulary—geometry, calculus, and quadratic equations—that allows them to describe many of the properties of the universe, from the relationship between the radius and the circumference of a circle to the behavior of subatomic particles. Its most famous epigram—$E=mc^2$—conveys in poetic shorthand the frozen energy of mass and the power to destroy cities.

But traditional physics has been unable to explain many common phenomena in nature, from the singularity of snowflakes to the self-organizing properties of neural networks in the human brain. Simply put, they are too complex. To inves-

PHOTOS: WOLFRAM RESEARCH INC.

"I wondered what would happen if we started from scratch and ignored everything that had been achieved in physics."

"He is wrestling with what is probably the hardest question in physics—the relationship between physics and computation. That is a pretty heady topic."

Danny Hillis, computer theoretician

tigate these phenomena, many scholars, including Wolfram, have turned to the emerging field of complexity theory. Complexity theory seeks explanations for apparently unpredictable phenomena—the flight of a swarm of bees, the ebb and flow of the stock market—in the interplay of their myriad simple components. In each case, individual actors—bees or brokers—make separate decisions based on simple rules; taken together, their actions create dynamic, apparently random patterns.

Wolfram and his colleagues believe the complexity of the universe belies an underlying simplicity in which a few basic rules give rise to complicated and unpredictable behavior. Indeed, if one conceives of God as a clever programmer, then one can imagine our vast, expanding universe as the elaborate consequence of an algorithm that set the conditions of the cataclysm known as the Big Bang. Everything that has followed—from black holes and organic chemistry to the rise of human consciousness and the spontaneous melody of a jazz improvisation—is an inevitable result.

Some of the rules that govern the behavior of the universe, we know: the laws of motion, the speed of light, the relationship between matter and energy. Others, however, may be embedded in systems so complex that they defy conventional analysis. To investigate the universe from this new perspective, scientists like Wolfram use computer simulations the way previous generations of scientists used microscopes, radio telescopes, cyclotrons, and particle accelerators. To the extent that the universe may behave like a computer obeying a programmer's instructions, they argue, computer models are the best device for learning how it works.

Wolfram says the computer experiments he has been conducting after hours at Wolfram Research in Champaign, Ill., have led him into a new world of basic science. The problem is, he won't tell anyone what he has discovered there. He has not published a formal research paper in years, nor has he presented his findings at any scientific conference though he does promise eventually to publish them in a book. Even close colleagues say they know only the general outlines of his work.

"Is there a simple computer that is the universe—a logical representation of how the universe fundamentally works?" Wolfram asks. "I will admit to having made quite a lot of progress on that question. It strongly encourages me to say the answer is yes."

But for now, that is about as much as he will reveal of his research.

With almost any other scientist, Wolfram's secretive midnight computer hacking might be dismissed as eccentricity or—less charitably—as the activity of someone unwilling to accept the consequences of his career choices. His erudite patter on the future of physics, modulated by his soft British accent, might seem just so much high-tech hyperbole, the kind of self-promotion that is as much a part of software packaging as shrink-wrap plastic. (This is, after all, a man whose corporate press release describes him as "one of the world's most original scientists.") So why is anyone listening?

"If I were less well known, people would just say, 'The guy is a nut case. Forget him,'" Wolfram admits.

But a remarkable number of respected computer scientists, physicists, and mathematicians seem, for the moment, to have suspended their disbelief. Some say they take Wolfram seriously because of his published record as a physicist, his work developing Mathematica, and the strength of his intellect. "Everybody, himself included, has been looking to him for a major contribution," says physicist Norman Packard, who helped Wolfram establish the Center for Complex Systems at the University of Illinois. The founder of a financial analysis firm in Santa Fe, N.Mex., Packard now applies complexity theory to help Swiss banks play the stock market.

Others stress the potential of the emerging field of computational physics. Neuroscientist Terry Sejnowski, who researches complex neural networks at the Salk Institute

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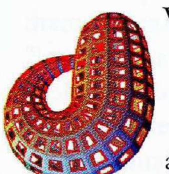
ROBERT LEE HOTZ reports on research and technology issues for the Los Angeles Times, *where he shared a 1994 Pulitzer Prize with his colleagues for coverage of the 1994 earthquake in Northridge, Calif.*

for Biological Studies in La Jolla, Calif., says Wolfram offers a "vision of the future of science"—a science "based on computational principles rather than the classical mathematical tools that so many generations of scientists have relied on."

"I think what he is doing goes to the bedrock of particle physics," Sejnowski says. "He is talking about a computational [model of the] universe based on quite new principles."

"If he succeeds he will make us rethink the world we are in," says Steven Levy, author of *Artificial Life*, an introduction to the emerging field of computer-driven complexity studies. "I think he has a shot at it."

CAMPUS CLASHES



Wolfram has come to Caltech to lecture on Mathematica as part of a 15-city tour to publicize the release of the newest version of the $1,295 software package. The encounter is also a personal homecoming of sorts for the 37-year-old CEO.

When he was barely out of his teens, the baby-faced doctoral student was Caltech's impatient wonder boy, a rising star whose work applying high-energy physics to cosmology was bright enough to attract the interest of Nobel laureates Richard Feynman and Murray Gell-Mann. But on this day at Caltech, mellowed by age, marriage, fatherhood, and commercial success, Wolfram no longer resembles the study in adolescent impetuosity who was known to choose his vacation spots simply by buying an airplane ticket to whatever destination appeared at the top of the departure board. Over a lunch of pork tenderloin and a green salad, Wolfram politely deflects personal questions about his wife, who is a mathematician, and his newborn child, out of privacy concerns prompted by the Unabomber case. But he talks eagerly about his extensive collection of seashells, the many dead ends of contemporary physics, and the proper role of a scientist in a free-market society.

A self-taught prodigy who never bothered with an undergraduate degree, the English-born Wolfram published his first paper on a problem in particle physics at 15. After stints at Eton and Oxford, he received his PhD in physics from Caltech at 20. At 21, he made headlines as the youngest person to receive a so-called genius grant from the MacArthur Foundation. The grant was based on the quality of his intellect more than on any single body of work and was intended to give Wolfram the freedom to step outside the mainstream, explains Kenneth W. Hope, an assistant dean of social sciences at the University of Chicago who administered the MacArthur grant program. "He was so remarkably smart," Hope recalls. "He dazzled a lot of people."

"Working with him [was] like playing basketball with Michael Jordan," says Rocky Kolb, a professor of astronomy and astrophysics at the University of Chicago, who coauthored 10 papers on high-energy physics and the nascent universe with Wolfram early in his career. "He pushes."

Indeed, his talent and ambition seemed to be matched only by his arrogance. Described as brash even by his friends, Wolfram had an "amazing lack of respect for the work of other people," Levy recalls. He hurried through a succession of prestigious faculty positions at Caltech, the Institute for Advanced Study at Princeton, and the University of Illinois, leaving patches of bad feeling smoldering behind him like a series of burned bridges.

He left Caltech after a dispute over the ownership of a computer programming language he developed. At Princeton, colleagues recall, his reliance on electronic computation seemed to unsettle older scientists more accustomed to slide rules and chalkboards. His impatience with academic formalities and faculty politics soon led him to relocate to Illinois, lured by the possibility of greater independence and the promise of quick tenure. At Illinois, however, Wolfram "stepped on a lot of toes," Packard says. "The political game of the university is a complex one and is not always amenable to the brash, demanding whiz-kid interloper." Again, impatience won out. And when he spurned academia for the business world, many

"I have spent the last 10 years doing the most obvious experiments. Of course, you often do not realize they are obvious until you have been thinking about it for years."

"Working with him was like playing basketball with Michael Jordan."

Rocky Kolb, professor of astronomy and astrophysics at the University of Chicago

MATHEMATICA IMAGES: MICHAEL TROTT

"If I were less well known, people would just say, 'The guy is a nut case. Forget him.'"

felt he had left his promise unfulfilled.

But in dozens of influential research papers, he had left his mark on physics, cosmology, computer science, and complexity theory. In 1981, for instance, he independently reinvented cellular automata, a concept that mathematicians John von Neumann and Stanislaw Ulam had created in 1953 for modeling complex systems on computers. Wolfram subsequently used them to create a widely used system for classifying complex phenomena. The publication of his papers on cellular automata helped to lay the groundwork for the development of the field of artificial life, a branch of complexity studies that uses computer modeling to simulate ecosystems and explore patterns of evolution.

Christopher Langton, director of the Artificial Life project at the Santa Fe Institute for Complex Studies in New Mexico, emphasizes the importance of Wolfram's work to the development of the field. "I don't think there is any doubt that Stephen Wolfram made fundamental contributions. His original work on the statistical mechanics of cellular automata singlehandedly revitalized the field and has served as the basis for countless other contributions by thousands of researchers around the world."

Wolfram was also a "prime instigator" in creating the field of computational physics—the use of computers to model problems in basic physics—notes Gerald Tesauro, a physicist at the IBM Research Division's Thomas J. Watson Research Center in Yorktown Heights, N.Y. To some extent, Wolfram's difficulties in academia stemmed from the interdisciplinary nature of this new field, which cuts across the organizational grain of academic departments, tenure tracks, and faculty prerogatives. According to his former collaborators, the physicist encountered considerable difficulty in obtaining funding for his work through conventional academic channels. Several computer scientists suggest that Wolfram may also have been handicapped by a lingering skepticism among some members of the scientific community about the true value of the kind of computer research he performs. Computer experiments, the skeptics say, are only elaborate electronic games with little or no connection to the real world. Indeed, the very first such computer program, a pattern-generating program called Life, was once distributed as part of a commercial package of computer games.

"There may have been some element of a question mark regarding the kind of science that Stephen represents," Packard says. "This kind of science is new and not exactly easy to take for the traditional scientific community. But I think it has more to do with the intrinsic difficulty—intellectually, politically, and culturally—of getting academic disciplines to really embrace interdisciplinary research."

Wolfram's impatience with the organizational constraints of academia matched his mounting frustration with the mechanics of coaxing computers to model the hypotheses he wanted to pursue, a dissatisfaction that drove him to develop Mathematica.

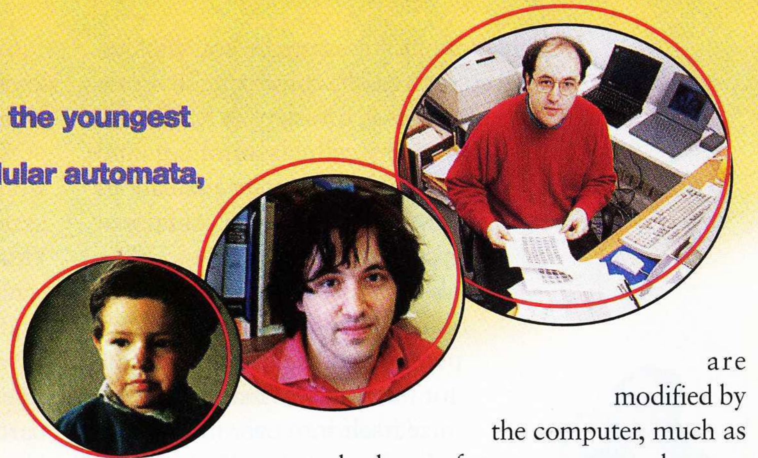
"Quite early on, I was interested in doing experiments on computers," Wolfram recalls. "One of the things that held me up was that I just didn't have the right tools to do what I wanted to do. I spent a lot of my days writing a lot of pieces of software to support these experiments. I realized this was silly. I was spending lots of time putting together tools which in some cases could be quite general tools, but I was putting them together for very specific computer experiments.

"'Maybe,' I thought, 'there is a better way to do this.'"

And what is Mathematica, exactly? Even Wolfram and his marketing department are hard pressed to give a simple description of this comprehensive mathematics processing program. Incorporating hundreds of math and physical constants and the world's largest collection of mathematical formulas, it offers a wide range of computational tools for scientists, engineers, and mathematicians interested in computer modeling and simulations. The program not only performs calculations but also generates graphics and provides the formatting tools of desktop publishing so that researchers can present their work.

It is a versatile tool shaped by each user's individual purpose. Researchers have used the software's modeling capabilities to solve problems as diverse as designing the bicycle track for the 1996 Olympic Games, predicting flow

Left to right: The future physicist, age four; the youngest MacArthur fellow, just starting to study cellular automata, 1982; Wolfram at work, 1995.

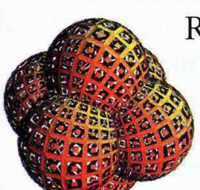


rates of molecules in commercial shampoos using various kinds of ingredients, and determining how tidal waves evolve as they sweep toward shore. So many computer-graphics artists have used Mathematica to create arresting geometric images that Wolfram opened an art gallery on his company's Web site. According to the company's estimates, a million researchers in 90 countries use the program, including all the *Fortune* 500 companies, the federal government, and the world's 50 largest universities.

The program has competitors, such as Mathcad, Scientific Workplace, and Theorist. But with the newest release of Mathematica—Version 3.0—last fall, Wolfram "established his superiority," says Columbia University civil engineering professor Gautum Dasgupta, who uses Mathematica to model the effects of major earthquakes. As head of an international teaching group, he also uses the program to develop computer tutorials for universities around the world. Dasgupta credits Mathematica's "overall comprehensive approach" with distinguishing it from other, more specialized programs. Other users note the program's emphasis on technical innovation—in which they see the characteristics of the man who designed it.

To produce the most recent version, Wolfram spent two years rebuilding the program from the ground up. Now he has vowed to reconstruct the world of physics, using Mathematica as the intellectual tool to do it.

THROUGH A MONITOR, DARKLY



Researchers like Wolfram turn their backs on the world outside the laboratory. They gaze instead through the windowpane of a computer monitor into a hypothetical universe, harnessing the power of the computer to explore the behavior of mathematical structures and complex systems.

Every computer program embodies an algorithm, or a set of instructions, that governs the way numerical data are modified by the computer, much as the laws of nature govern the way objects behave in the real world. To conduct experiments on a computer, Wolfram explains, researchers use numbers or symbols to represent objects and then manipulate them according to the rules they have established. "My work is all really based on one big idea: that everything can be expressed as a symbolic expression," he explains. Because these kinds of simulations can be performed in a hypothetical universe rather than one bound by the laws of nature, he argues, computer experiments represent "a new kind of science."

When Wolfram first turned his attention to complexity studies in the early 1980s, he was looking for a way to explain complex phenomena—the patterns on mollusk shells, the behavior of molecules swirling in turbulent fluid, and fluctuating prices on the stock market. "I tried to use methods from statistical mechanics and various other quite formal, sophisticated areas of physics and I was fairly disappointed that I did not get very far using these conventional methods," Wolfram says. "It is quite plain that the [conventional] approach has been a failure for biology and studying more complex physical systems."

Instead, he developed a computer-modeling device called cellular automata. Cellular automata are self-replicating, self-organizing groups of cells that live, die, and form patterns based on simple rules that instruct each cell to change its behavior in accordance with the behavior of neighboring cells. They provide a uniquely useful tool for scientists studying how the interaction of individual elements influences a system as a whole. As in nature, it is extraordinarily difficult to predict what pattern will result from a given set of rules. The only way to find out is to set the initial conditions and let the program run.

"I found that very simple rules, instead of producing fairly simple behavior, actually produce extremely complicated behavior," Wolfram says. "That is a piece of intuition that many people just haven't got yet. When you see a complicated phenomenon in nature, your instinct is to try and make a complicated model to explain it. Somehow, nature itself does not need that. People don't understand that there are really simple experiments that can tell you really interesting

things about, for example, how biological systems can be constructed."

Scientists in a variety of fields have begun using cellular automata and other kinds of computer simulations to investigate questions traditional physics can't answer. Physicist Per Bak at Brookhaven National Laboratory is looking into his computer for a theory that accounts for the ability of matter to organize itself into ever more complex forms. Stuart Kauffman at the Santa Fe Institute is investigating self-organizing behavior as a key to understanding the origin of life. Langton at the Santa Fe Institute is developing standardized computer programs to allow researchers to study complex systems, from a collection of single-celled animals in a pond to a group of competing companies.

"It may sound arrogant, but I have moved pretty far away from what most scientists know about. I am my own reality check."

"He is hurting himself by not interacting more with the scientific community."

A former Princeton University colleague

But Wolfram, once again, is going his own way. In his view, much of the research into complexity is "impenetrable nonsense" with "a fair amount of rhetoric and not much science." But when it comes to trying to explain his own work, he shares the difficulty: "I am talking about concepts that are reasonably fundamental and reasonably abstract. That means most words that describe it sound vacuous."

Where many researchers are using complexity studies to explore biology, Wolfram says he is exploring the underlying order of the universe itself. "I wondered what would happen if we started from scratch and ignored everything that had been achieved in physics, to see what we could do," he says. "I have spent the last 10 years doing the most obvious experiments. Of course, you often do not realize they are obvious until you have been thinking about it for years."

Computational physics "is a great field because nothing is known, absolutely nothing," he declares. "There is a computer universe there that just has not been looked at."

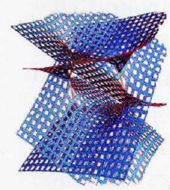
Wolfram is somewhat sheepish about the secrecy of his work, but says he simply wants to work undisturbed by intellectual competition. Not everyone is bothered by his silence. "Maybe Stephen has a really good idea but is just being very careful about building a solid case for it," Langton says.

Colleagues around the country say Wolfram has alluded to some of his findings in Internet exchanges with a few key researchers. "He is wrestling with what is probably the hardest question in physics—the relationship between physics and computation. That is a pretty heady topic," says Danny Hillis, an influential computer theoretician who pioneered the concept of massive parallel processing, the basis of most new supercomputer designs.

"He has given only tantalizing hints as to what the answers he has found would be," says Kolb at the University of Chicago. "He seems confident he is on to something."

"He is looking for some deep connections between fundamental physics and fundamental ideas in computer science," says Gregory J. Chaitin, a noted mathematician at IBM's Watson Research Center. The idea that the way the universe works is analogous to the way computation works "is a very intriguing idea that a number of people have speculated on, but there has been no serious work. Maybe he won't find anything. But maybe he will find something very interesting indeed."

A SCIENTIST WITHOUT PEER



Whether Wolfram succeeds or fails as a physicist, the manner in which he has chosen to pursue his research poses some provocative questions for the practice of science.

What sets Wolfram apart is his insistence on working independently, not just without collaborators but also without the supporting superstructure of the conventional research establishment: he relies on his own funding and equipment and has no one to answer to but himself.

"My view about doing basic science," he explains, "is that if you have no choice, then getting paid by a university is a fine thing to do. If you have a choice, there are a lot better ways to live.

"As CEO of a company, the fraction of my time that I get to devote to basic science is probably much larger than the fraction of time that a typical senior professor at a university would devote to basic research. If you are a senior university professor, you are out raising money from the government, being on committees, and teaching classes. It is only in the extra bonus time that you get to do research."

Wolfram says he wants to revive an older tradition in

which people pursue science as a personal calling, whether or not they are the beneficiaries of public patronage. Too many scientists today, he says, give up their research simply because they can't get the public to pay for it. Indeed, one of the attractions of computational research, he says, is that it requires nothing more expensive than a personal computer.

"I don't have to beg the government," he says. "I don't have to convince anyone at the National Science Foundation that what I am doing is not as nutty as they might assume or as the peer review system might say it is."

No public funding, however, means no real obligation to communicate his findings, and no need to submit himself to peer review. "It may sound arrogant, but I have moved pretty far away from what most scientists know about," Wolfram maintains. "That means there are fewer and fewer people I can talk to about what I am doing. Your typical top scientist does not know this stuff.

"I am my own reality check," he concludes.

Some researchers say Wolfram is blazing a path for other scientists to follow. With full-time faculty research jobs scarce and funding for basic industrial research increasingly rare, many scientists are seeking new ways to balance the demands of commerce against the lure of knowledge for its own sake. And the idea of financial independence is becoming more attractive.

By creating a software company to support his work, "he has built a new model for funding science—the scientist as entrepreneur, rather than the scientist as public welfare recipient," says Sejnowski at the Salk Institute. Wolfram, he says, reminds him of Edwin Land, who founded Polaroid and then continued to pursue basic research into the physics of color and vision in his corporate lab.

"In starting your own business," physicist-turned-entrepreneur Packard concurs, "you don't have to deal with the same kind of political complexities, and you don't have to tolerate a lot of the bull you have to tolerate in a university. You are not at the whim of the scientific culture of some funding agency."

There is certainly no shortage of iconoclastic loners in contemporary science. Princeton University mathematician Andrew Wiles spent seven years working secretly in his attic to polish a 200-page proof of Fermat's Last Theorem, one of the most famous problems in his field. When he unveiled his solution in a series of dramatic lectures in 1993, he made headlines around the world. Only then, however, did a sharp-eyed graduate student spot—and help fix—a critical error.

Indeed, the aloofness that Wolfram considers one of his virtues, others see as self-defeating. "He is battling with himself when he chooses to work in complete isolation," one former Princeton University associate says. "He is hurting himself by not interacting more with the scientific community at large."

Other colleagues worry that his research muse has become a computer widow. In the past 18 months, for example, he has had little opportunity to brood on basic science, concentrating instead on polishing the new release of the program. They question whether Wolfram will ever be willing to loosen his hold on company operations enough to permit sustained, reflective research. While admiring his commercial success, they worry that he has been sidetracked by his tools—like a sculptor who spends all day sharpening her chisels but never sets one to marble, or a novelist who spends all day fiddling with the fonts in his word processing program.

"He has invested a lot of time in [Mathematica]," Hillis says. "That is great for the rest of us who use it, but it is probably bad for physics."

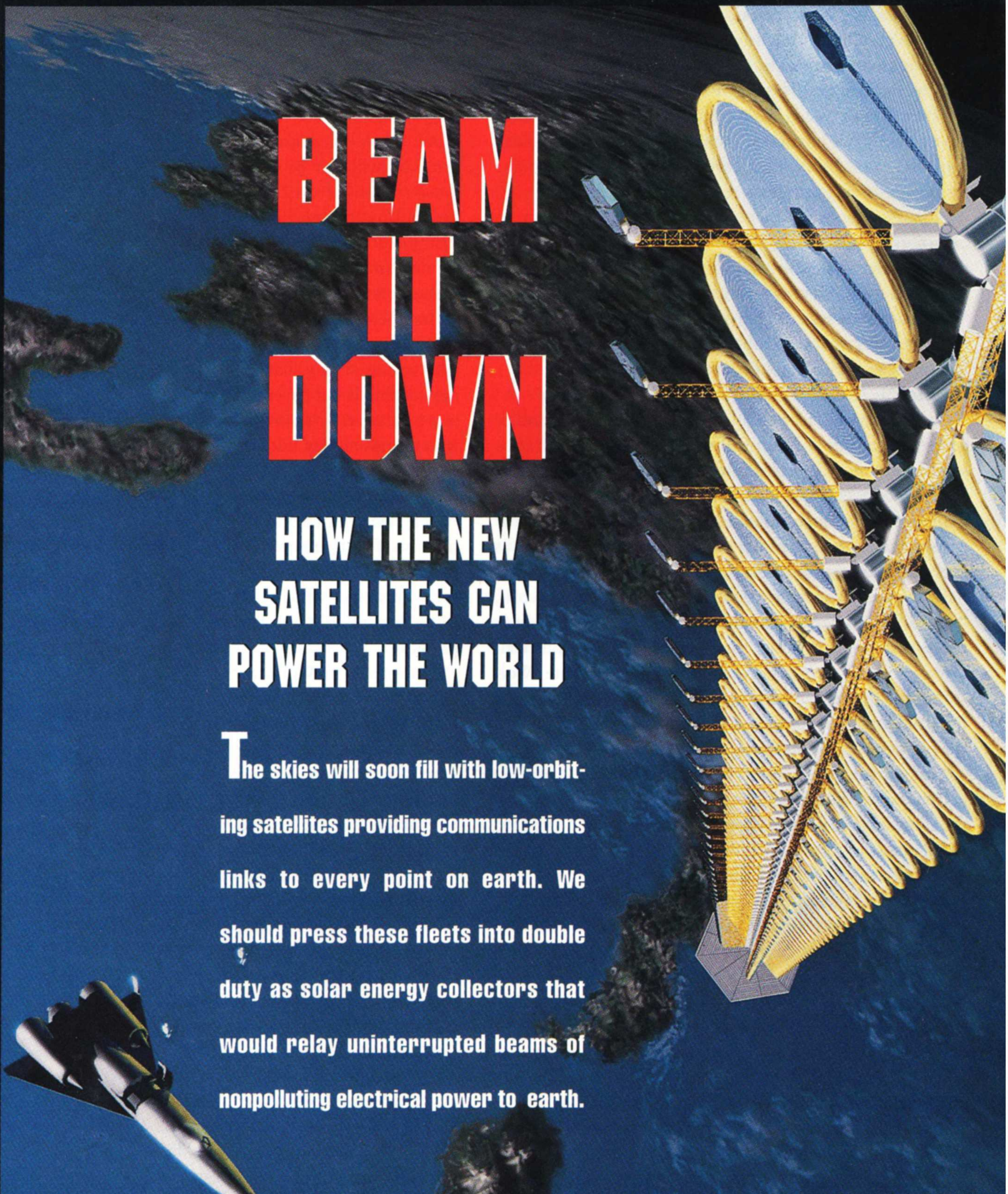
The program Wolfram developed to facilitate his own research may, in the end, overshadow it; the man who sought such a prominent place in the history of science may have to settle instead for a mention in his own company's annual reports. But as the scientific community waits and watches, it is not yet clear how this particular high-wire act will end. Wolfram remains balanced delicately on the tightrope of his ambitions.

"I seriously doubt that Stephen would set himself up for the fall he would take if he never delivers on the promise," Langton says. "I am willing to place my bets on Stephen, even though I don't know when they might pay off." ■

"It is quite plain that the [conventional] approach has been a failure for studying more complex physical systems."

"If he succeeds he will make us rethink the world we are in."

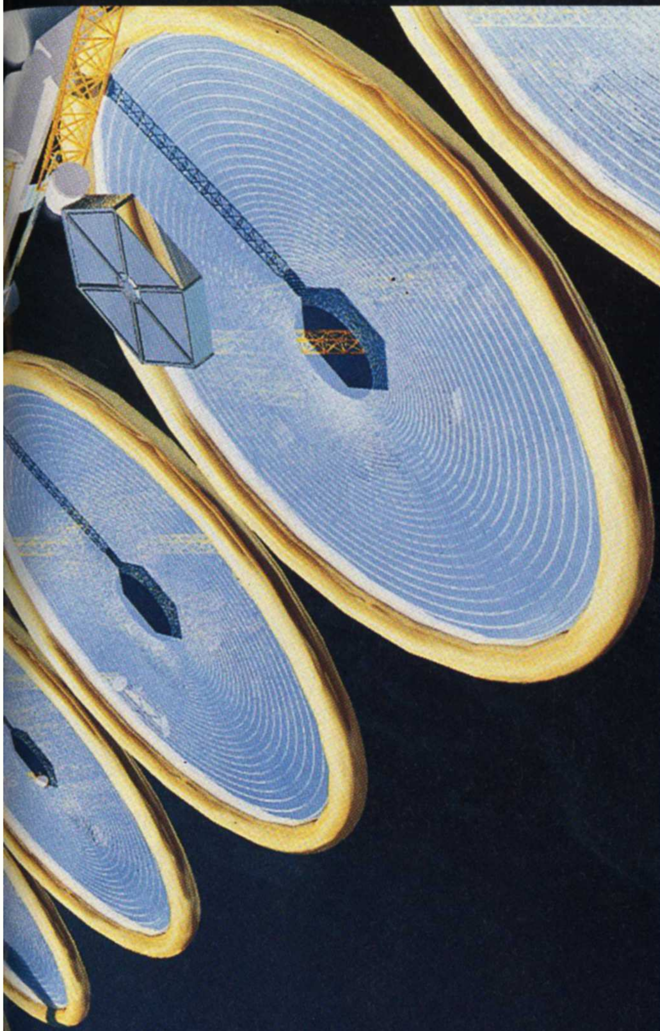
Steven Levy, author of Artificial Life



BEAM IT DOWN

HOW THE NEW SATELLITES CAN POWER THE WORLD

The skies will soon fill with low-orbiting satellites providing communications links to every point on earth. We should press these fleets into double duty as solar energy collectors that would relay uninterrupted beams of nonpolluting electrical power to earth.



BY MARTIN I. HOFFERT AND SETH D. POTTER

IN OUTER SPACE,

the sun always shines brightly. No clouds block the solar rays, and there is no nighttime. Solar collectors mounted on an orbiting satellite would thus generate power 24 hours per day, 365 days per year. If this power could be relayed to earth, then the world's energy problems might be solved forever.

Solar power satellites (SPS) were originally proposed as a solution to the oil crises of the 1970s by Czech-American engineer Peter Glaser, then at Arthur D. Little. Glaser imagined 50-square-kilometer arrays of solar cells deployed on satellites orbiting 36,000 kilometers above fixed points along the equator. A satellite at that "geosynchronous" altitude takes 24 hours to orbit the earth and thus remains fixed over the same point on earth all the time.

The idea was elegant. Photovoltaic cells on a satellite would convert sunlight into electrical current, which would, in turn, power an onboard microwave generator. The microwave beam would travel through space and the atmosphere. On the ground, an array of rectifying antennas, or "rectennas," would collect these microwaves and extract electrical power, either for local use or for distribution through conventional utility grids.

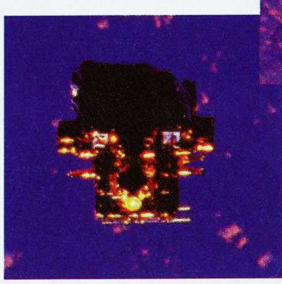
The technology, as originally envisioned, posed daunting technical hurdles. Transferring electrical power efficiently from a satellite in geosynchronous

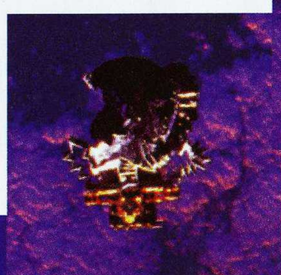
ILLUSTRATION BY PAT RAWLINGS

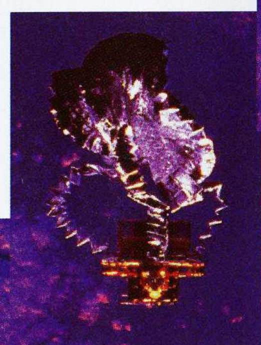
orbit would require a transmitting antenna on board the satellite about one kilometer in diameter and a receiving antenna on the ground about 10 kilometers in diameter. A project of this scale boggles the mind; government funding agencies shied away from investing immense sums in a project whose viability was so unclear. NASA and the Department of Energy, which had sponsored preliminary design studies, lost interest in the late 1970s.

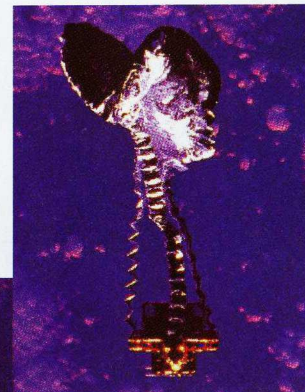
In the last few years, however, the communications industry has announced satellite projects that suggest the time has come to revisit the solar power satellite idea. By early in the next century, swarms of communications satellites will be orbiting the earth at low altitude, relaying voice, video, and data to the most remote spots on earth. These satellites will relay communication signals to earth on beams of microwaves. The transmission of electrical power with a beam of microwaves was demonstrated as early as 1963, and projecting power and data along the same microwave beam is well within the state of the art. Why not use the same beam to carry electrical power?

The new communications satellites will orbit at an altitude of only a few hundred miles. Instead of hovering above a spot on the equator, low-orbiting satellites zip around the globe in as little as 90 minutes, tracing paths that oscillate about the equator, rising and dipping as many as 86 degrees of latitude. Because they are closer to the earth's surface, the solar collectors on the satellite can be a few hundred meters across rather than 10 kilometers. And because the microwave beams they generate would spread out much less than those from geosynchronous satellites, the ground rectennas could be correspondingly smaller and less expensive as well. By piggybacking onto these fleets of communications satellites—and taking advantage of their microwave transmitters and receivers, ground stations, and control systems—solar power technology can become economically viable.









Low earth orbit poses its own difficulties, though. Because they whip around the planet so quickly, low-orbiting satellites must possess sophisticated computer-controlled systems for adjusting the aim of the microwave beam so that it lands at the receiving station. These satellites will have to use sophisticated electronic systems, called phased arrays, to continuously retarget the outgoing beam.

Martin I. Hoffert is a professor of physics at New York University. Seth D. Potter is a research scientist in physics at New York University. This article is adapted from Solar Power Satellites: A Space Energy System for Earth, *edited by Peter Glaser and published this summer by Oxford University Press.*

ENERGY FOR DEVELOPMENT

The demand for space-based solar power could be extraordinary.

By 2050, according to some estimates, 10 billion people will inhabit the globe—more than 85 percent of them in developing countries. The big question: How can we best supply humanity's growing energy needs with the least adverse impact on the environment?

Dependence on fossil fuels is not the answer because burning coal, oil, and gas will pour carbon dioxide into the atmosphere, raising the risk of global climate change. (And of course these resources will not last forever.) Nuclear fission reactors avoid the greenhouse problem but introduce the so-far intractable problem of disposing of nuclear waste. Controlled nuclear fusion might someday provide an inexhaustible supply of clean energy—but after forty years of continuous funding, a practical fusion reactor is still not in sight.

That leaves the menu of renewable energy sources. But terrestrial renewables pose environmental problems because of their relatively large land requirements. Hydropower, the most exploited renewable thus far, has significantly disrupted ecosystems and human habitats. Solar, biomass, and wind farms would similarly compete with people, agriculture, and natural ecosystems for land were they the basis of a global energy system.

Moreover, ground-based renewable energy systems, such as terrestrial photovoltaics and biomass fuels, generate fewer than 10 watts of electricity per square meter, on a continuous basis. To generate enough electricity to meet demand could require developing countries either to divert land from agricultural use, and thus diminish the supply of food, or to destroy natural ecosystems, a move that could hasten the onset of global warming.

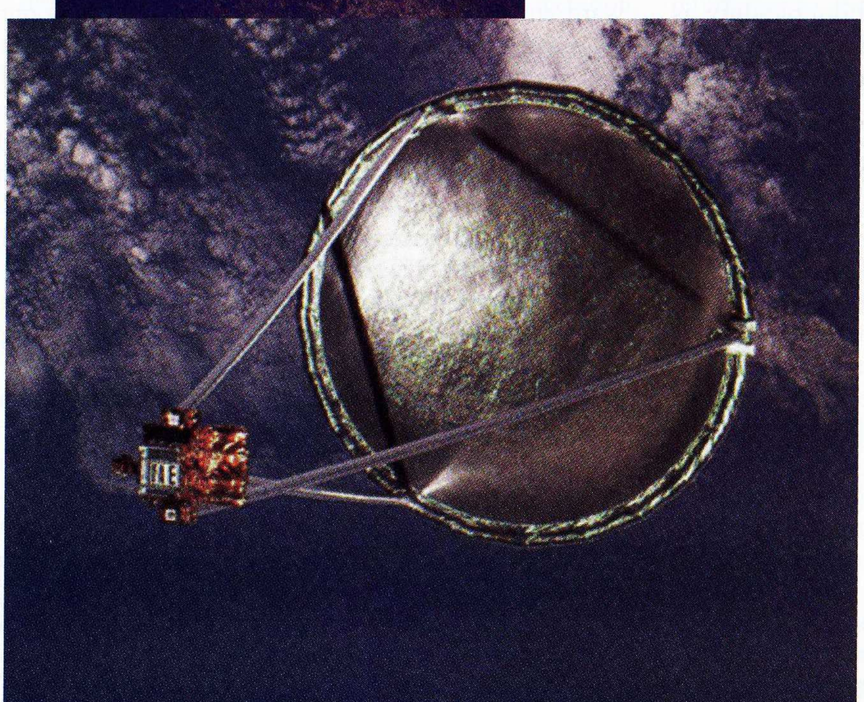
Solar power satellites would require far less land to generate electricity. Each square meter of land devoted to the task could yield as much as 100 watts of electricity. And the power-receiving rectenna arrays—a fine metallic mesh—would be visually transparent, so their presence would not interfere with crop growth or cattle grazing.

And the flow of power from terrestrial renewables is intermittent. Clouds blot out the sun; the wind stops blowing; lack of rainfall nullifies a hydro generator. Because these technologies do not deliver power continuously, they require some means of storing energy, adding to overall cost and complexity. A network of solar power satellites in low earth orbit could provide power to any spot on earth on a virtually continuous basis because at least one satellite will always be in "view" of the receiving station.

Unfortunately, solar power from space is not yet on the official menu of twenty-first century energy options. Since the 1970s, NASA and the U.S. Department of Energy have provided only token funding for the technology. A recent study by the National Academy of Sciences of potential strategies to mitigate global warming analyzed a wide range of nonfossil energy alternatives—including nuclear, hydroelectric, geothermal, solar photovoltaic, solar thermal, wind, and biomass energy—but did not include space power as an option.

Despite the funding desert in the United States, work on solar power satellites has continued elsewhere. In Japan, for example, leaders of the New Earth 21 program at the Ministry of Technology and Industry (MITI) view space solar power as "an essential part in the proper control of CO_2 levels." MITI has sponsored the design of a kite-like orbiter that would travel in low earth orbit above the equator, with transmitting antennae on the earthward face and solar collectors on spaceward faces.

In the United States, commercialization of space power will become a reality only if it can attract investment capital and succeed as a business. Fortunately, the private sector seems eager to invest in the communications satellites that could provide the vehicles for a solar power satellite. Motorola, for example, is putting $3.8 billion into Iridium, a venture comprising 66 communications satellites in low earth orbit. Teledesic Corp.—a joint venture of Microsoft chairman Bill Gates and cellular phone tycoon Craig McCaw of Mobile Telecommunications Technologies—plans to spend $9 billion to deploy 288 satellites. *(See "High Hopes for Low Satellites," page 35.)*



An inflatable antenna (near left), 50 feet in diameter, unfurls in space from a satellite (left to right). This 1996 NASA experiment demonstrated the feasibility of inflating solar collectors in orbit, which could deliver large amounts of power to the earth via microwaves.

LOOKING FOR A CHEAP LAUNCH

One important consideration in planning space power is the expense of putting a satellite into orbit. Right now, it costs a thousand times more to put an object into space than to fly it across country by commercial airliner, even though the two jobs require roughly the same amount of energy—about 10 kilowatt-hours per kilogram of payload. Two factors account for the extra cost: the army of engineers and scientists required for a successful space launch, and the practice of discarding much of the launch vehicle after each flight.

Launch costs are likely to drop, however, as the demand increases for hoisting large volumes of material into space on a regular basis: the more frequently a launch system is used, the lower the cost per use. Moreover, NASA is seeking a new generation of reusable launch vehicles. The agency recently sponsored a competition among aerospace contractors for a space vehicle with the potential for airline-like operation. The winner was Lockheed Martin Skunk Works, legendary innovators in aircraft design from the U-2 to the Stealth fighter. Lockheed Martin plans to build and test the $1 billion wedge-shaped reusable X-33 —a one-half size, one-eighth mass version of a launch vehicle called Venture Star that would replace the space shuttle for ferrying cargo into low orbit. The target launch cost is $2,200 per kilogram—one-tenth that of a shuttle launch. At that price, space power could become cost-effective if satellites pull double-duty as communications relays and solar-power sources.

Japan's SPS 2000 satellite, with a microwave transmitter on one face and solar collectors on the other two faces, was designed to demonstrate the idea of beaming orbitally collected solar energy to earth from satellites.

A solar power satellite should quickly pay back the energy needed to put it into orbit. Start with the conservative assumption that solar power satellite technology would produce 0.1 kilowatt of electricity on the ground per kilogram of mass in orbit. In that case, the energy expenditure of 10 kilowatt-hours per kilogram to lift the satellite into orbit would be repaid in electricity after only 100 hours—less than five days.

One way to keep launch costs down is to use an inflatable structure as the solar collector. Doing so would maximize the collector's surface area—important to gathering the greatest amount of solar energy—without imposing a major weight burden on the launch vehicle. Deflated solar collectors could be folded into a compact space on board the spacecraft; once in orbit, gas from a pressurized container would inflate the structure.

Balloons in space are an old story. In fact, the 1960-vintage satellite known as Echo I was a balloon used to bounce radio waves back to Earth. NASA is now studying the feasibility of inflatable structures in space for antennae, sunshades, and solar arrays, although not explicitly for solar power satellite systems. An important experimental milestone was the successful deployment by Space Shuttle Endeavour astronauts in May 1996 of the Spartan Inflatable Antenna Experiment—a 14-meter antenna inflated by a nitrogen gas canister in orbit.

It is not such a very large step from such an experiment to a solar-collecting satellite that could be assembled in orbit from inflated segments. Were NASA to make research on inflatable space structures a high priority, the knowledge base to make cost-effective low-mass power satellites could evolve rapidly.

ONE STEP AT A TIME

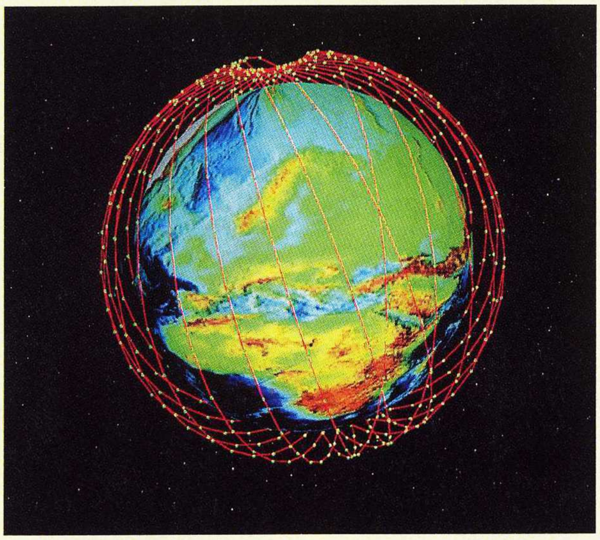
At first, the solar energy relayed from space would be used only to provide the minimal electrical power needed to run the electronics of the receiving station on the ground—much the way that line current powers conventional telephones. Ultimately, the satellites would beam down larger amounts of power, which could provide the megawatts of electricity that would contribute substantially to powering a village or even a city.

Scaling up to higher power levels would be straightforward, entailing simply the deployment of a larger amount of solar-collecting area in space. Power would be transmitted through the infrastructure of transmitters and receivers that will then be in place for the satellite communications systems. In this regard, microwave transmission has a decided advantage over conventional cable methods of transmitting power. A microwave system that is 80 percent efficient at sending 1 kilowatt will still be 80 percent efficient at sending 1 megawatt. This is fundamentally different from an electric utility transmission line, where you need thicker, and costlier, wires to carry more power. If too much power is put through a cable, it will melt the insulation.

Some fear that a network of solar power satellites could turn the atmosphere into one big microwave oven, cooking whatever wanders into the beam's path. In reality, the microwave intensities that we propose would be orders of magnitude below the threshold at which objects begin to heat up. People would be exposed to microwave levels comparable to those from microwave ovens and cellular phones. While some critics speculate that microwaves pose nonthermal threats to human health, there is no reliable epidemiological evidence for adverse effects from microwaves at these low levels. Higher levels of microwave radiation would be

PHOTO: JAPANESE INSTITUTE OF SPACE AND ASTRONAUTICAL SCIENCE

HIGH HOPES FOR LOW SATELLITES



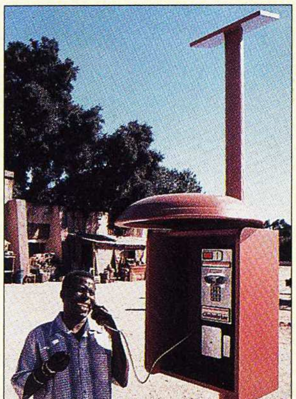
Communications companies are planning to launch dozens of satellites in the next decade—extending the global communications network to remote areas and forming an orbiting infrastructure for collecting solar power.

THE promise of cheap solar power from space hinges on a new generation of communications satellites. These low-earth-orbit (LEO) satellites will loop around the earth at an altitude of 400 to 1,000 miles—about 20 to 50 times closer to earth than conventional geosynchronous satellites, which remain fixed over the same point on earth. The systems under development will provide a range of communications services, from simple e-mail and paging to realtime voice communications and, in some cases, multimedia access to the Internet.

One LEO project—the Orbcomm system developed by Orbital Sciences Corp. in Dulles, Va.—launched its first two suitcase-sized satellites in 1995, and hopes to place 36 satellites in orbit by next year. This system will offer users worldwide data communications—electronic mail, fax, and paging—by way of small handheld devices. The satellites' small size—roughly 95 pounds—translates directly into lower launch costs. According to Orbcomm, the entire 36-satellite constellation will cost about $330 million—roughly the cost of a single geosynchronous satellite.

Globalstar—a San Jose-based limited partnership led by Loral Space and Communications and Qualcomm—will begin launching a 48-satellite system this fall. Globalstar subscribers will use special telephones that will work like ordinary cellular phones when in range of a cellular station but that will automatically route their signals to a Globalstar satellite when the user roams outside the covered area. The satellite beams the call back down to a ground-based gateway, which will direct it into a conventional telephone system in the area being called.

Globalstar has already secured the $2.5 billion to get this system into operation, according to David Benton of Loral Space and Communications, the managing partner for Globalstar. Investors include Daimler-Benz Aerospace, Hyundai, and France Telecomm. "The final hurdle is regulatory," Benton says. The company will need agreements with every country in which they plan to operate.



Satellites for another LEO system, called Iridium, began entering orbit this spring and summer. Iridium will provide voice, data, fax, and paging services through a cellular phone-like device that will transmit directly to a satellite. The signals will jump from one satellite to another and eventually return to an earth-based Iridium gateway that will connect to conventional telephone networks. So far, 17 out of a planned 66 satellites have been launched by Iridium LLC, an international consortium of telecommunications and industrial companies. Iridium was conceived by Motorola, which has been selected as the prime contractor to design and build the system. The rest of the network is to be deployed throughout 1997 and early 1998, with commercial service to commence late in 1998.

Teledesic Corp. in Kirkland, Wash., plans the most satellite- and capital-intensive system, expecting to launch several hundred LEOs for $9 billion to form a system that would begin operation in 2002. The satellites will provide high-speed data communications at up to 1.2 billion bits per second, broadband Internet access, and realtime videoconferencing anywhere on the globe. It will be the "satellite equivalent of fiber optics," says Teledesic spokesperson Roger Nyhus.

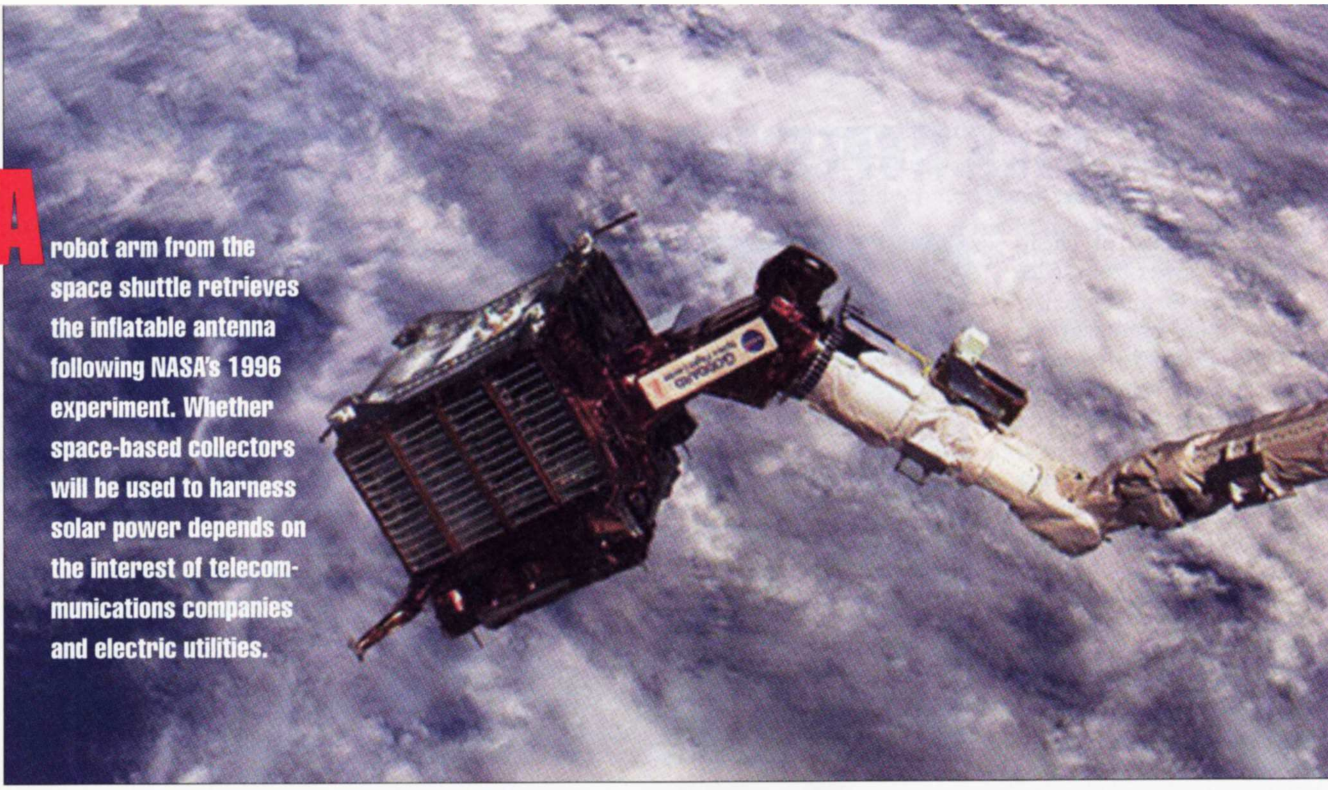
This project demands very deep pockets, and this company enjoys some of the deepest; its founding investors are Craig McCaw, a pioneer in cellular phones, and Bill Gates of Microsoft. The company recently added Boeing as an equity partner; Boeing will design, build, and launch the system. Upon joining the enterprise, Boeing quickly pared down the system from the original plan of 840 satellites to a more easily attainable 288 satellites.

The advent of LEO communications satellites can potentially knit the world together better than any wired system. Individuals will "have the capability to have one cell phone that will operate anywhere in the world," says Ray Peterson, a space systems analyst at Forecast International of Newtown, Conn. "It will give people the ability to communicate with anyone from anywhere." ■

—*Mike May*

MIKE MAY is an associate editor at American Scientist.

PHOTOS: GLOBALSTAR



A robot arm from the space shuttle retrieves the inflatable antenna following NASA's 1996 experiment. Whether space-based collectors will be used to harness solar power depends on the interest of telecommunications companies and electric utilities.

found at the rectennas on which the beams are focused, but fences and warning signs could demarcate these areas of possible danger. But according to our calculations, microwave intensities even at the perimeter of the rectenna would fall within the range now deemed safe by the Occupational Safety and Health Administration.

A bigger potential problem is that of sharing the limited frequencies in the microwave spectrum. Motorola has come under fire, for example, because its planned system will employ frequencies in the 1.616-to-1.626-gigahertz range, which almost overlaps the 1.612-gigahertz frequency that astrophysicists tune to when gathering data about the cosmos. Radio astronomers worry that interference from a solar power satellite will overwhelm the comparatively weak signals they are seeking to detect. Motorola promises to limit spillover of its communications beams into the radio astronomers' frequency niche, but the issue underscores the fact that the microwave spectrum is a limited resource jealously guarded by commercial and nonprofit users alike. Allocation of the spectrum must be addressed promptly and effectively to avoid preemption of space power technology before it's born.

Whether solar power satellites become a reality will ultimately depend on the willingness of telecommunications and electric utility companies to enter the space power business. So far, neither industry has shown much interest. But then, they are for the most part unaware of the commercial possibilities. One has to know that an option exists to choose it. Thirty years ago, communications satellites were a novelty. Ten years ago, no one had heard of the Internet.

What is certain is that the present push for deregulation has led to a scramble on the part of telecommunications, computer, cable TV, and utilities industries to enter each others' markets. Some electric power companies want to enter the telecommunications business as a way of capitalizing on the huge investment in wire and cable that reaches virtually every building in the country. It makes equal sense to propose that communications companies enter the power business. In practice, consortiums of power and communications companies might develop the proposed technology together.

No single piece of this technology poses a fundamental stumbling block. The physics of photovoltaic cells and microwave generation are well understood. To move to the next stage, though, will require a demonstration that all the pieces of this system can work together: the solar panels, the phased-array microwave antennas, the receiving stations that separate the data signals from the power beams, and the computers that tell the satellites where on the ground to aim the beams. NASA could accelerate this development tremendously by placing into orbit a prototype of a solar power satellite.

The benefits are too large to walk away from. A network of solar power satellites such as what we propose could supply the earth with 10 to 30 trillion watts of electrical power—enough to satisfy the needs of the human race through the next century. Solar power satellites thus offer a vision in which energy production moves off the earth's surface, allowing everyone to live on a "greener" planet. Consider the philosophical implications: no longer need humankind see itself trapped on spaceship earth with limited resources. We could tap the limitless resources of space, with the planet preserved as a priceless resource of biodiversity. ■

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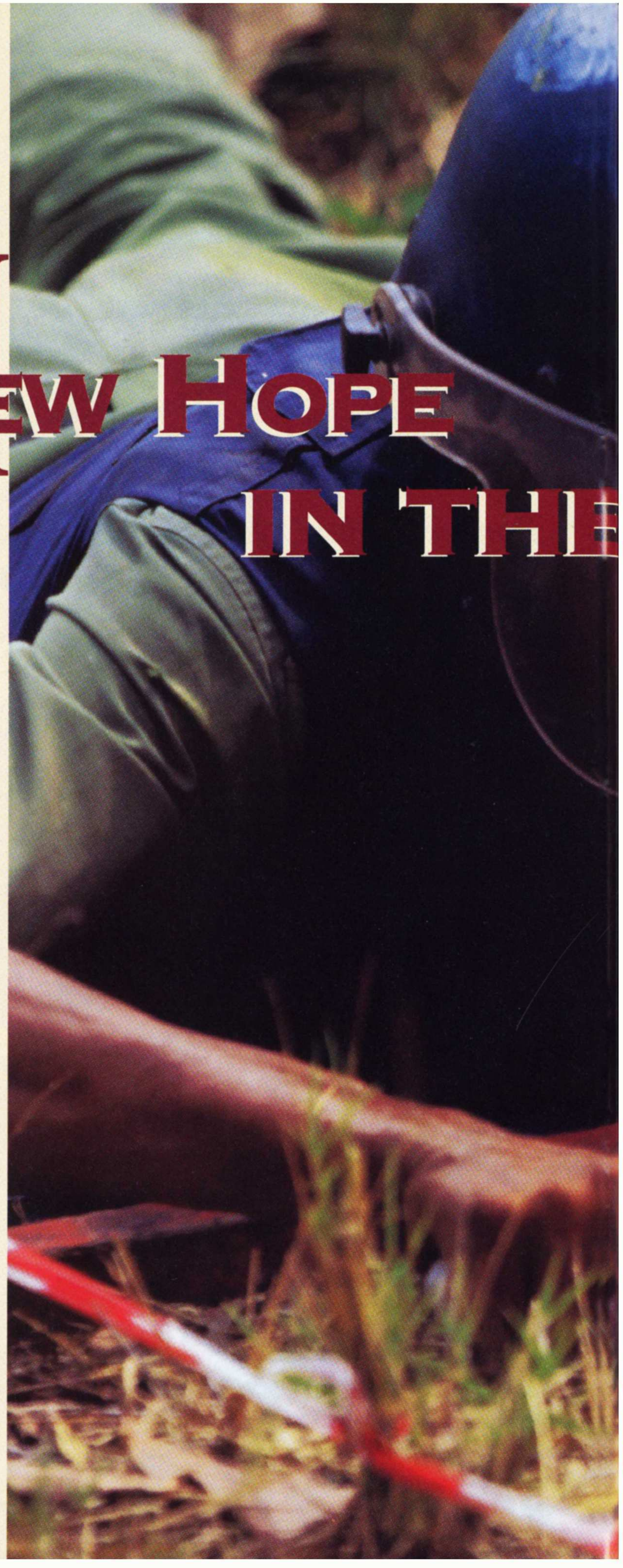
PHOTO: NASA

Emerging technologies can speed the removal of the millions of buried landmines that continue to kill and maim civilians in more than 60 countries.

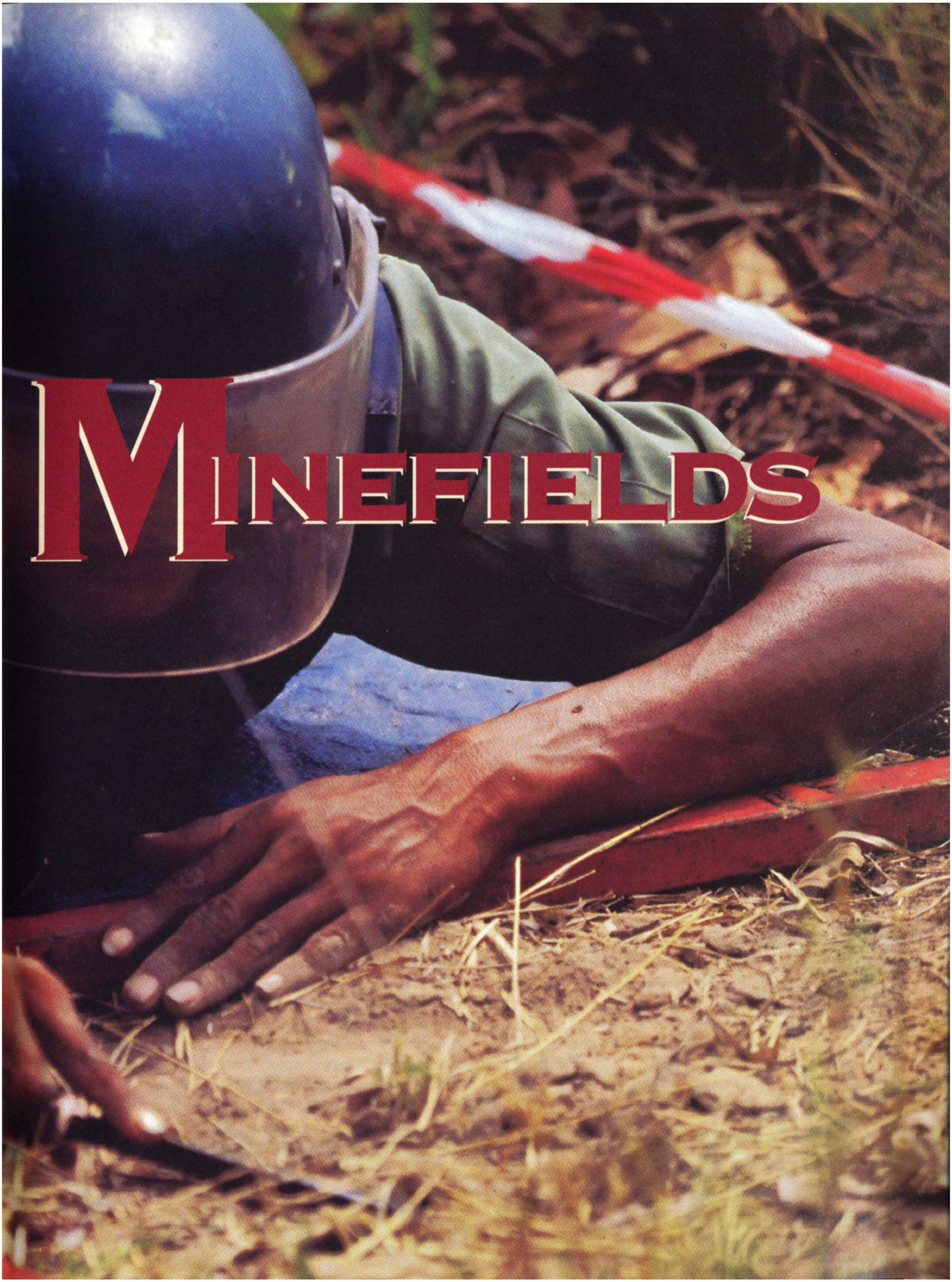
New Hope in the

BY
PHILIP MORRISON
AND
KOSTA TSIPIS

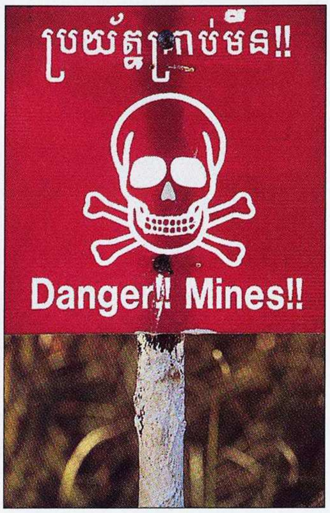


Stepping gingerly along a path at the edge of a weed-ridden farm in Cambodia, a man listens carefully as he sweeps his metal detector over the ground. When the detector's squealing tone signals the presence of buried metal, the man stops, repeats the sweep, and carefully marks the spot. Soon a second worker follows and lies on the ground, his head an arm's length from the marked spot, gently probing the ground with a stick. Both men are experienced deminers, one a retired British Army veteran far from home, the other a local resident trained to find mines. Both know

PHOTO BY DAVID A. FEINGOLD



MINEFIELDS



Affordable technologies could be in place within 5 years for a demining effort on an unprecedented global scale.

well the costs: sudden serious injury or death.

After probing the hard dirt with concentrated care for about 20 minutes, the prone worker judges by sight and feel whether he has hit the rounded metallic body of a buried mine or merely the random detritus of an old battlefield: a bullet, a piece of shrapnel, a length of wire, an empty tin can. He knows that in some fields the odds are as low as one in a few hundred that the detected metal is actually a mine, but his partner's metal detector cannot distinguish an explosive device from any other object that holds a fraction of an ounce of metal.

Whatever it is, the metallic object must be carefully exposed to reveal its form and color. If it is a mine the workers will place a modest explosive charge beside it, unspool long wires, and retreat 100 yards to blow it up. Then the task will repeat itself: the operator of the metal detector will resume his patient sweeping, listening for signs of the next buried metallic object in his path while his partner waits for his next tense trial in the dirt.

According to United Nations estimates, more than 100 million mines lie buried around the world, outlasting their wars, abandoned long ago yet awaiting their unintended victims for as long as decades. An anti-personnel mine costs only a few dollars to produce, but it now costs a hundred times that sum to remove it. In Cambodia alone, where some of the world's densest minefields lay, roughly 10 million mines lurk within an area the size of Missouri. Last year three thousand workers cleared landmines from 12 square kilometers of Cambodian land at a cost of $8 million. They were not overpaid. But at that rate, even if someone were willing to foot the bill, demining Cambodia would take some 10,000 years. To make matters worse, participants in today's conflicts are emplacing new mines at a rate 10 or more times the current yield of the deminers, who now clear perhaps 100,000 mines per year worldwide. A chronic and growing crisis is at hand.

Most poignant is the human toll that the residual landmines claim: some 10,000 deaths annually and at least twice that many serious injuries, with victims including many small children and elderly villagers in poor nations. In Cambodia, landmine accidents have resulted in one amputee per 250 people. Yet clearing away lingering landmines is not needed just to protect human life and limb. Over the long term, landmines disrupt normal economic activities such as travel and transport, and deny vital cropland to farmers, often causing hunger and forcing sizable agrarian populations to migrate to urban centers and refugee camps.

Today, the use of a metal detector, hand-held probe, and explosive charge is generally accepted as the most reliable demining method despite its laborious and perilous nature. The detection method works because most mines have metallic casings or at least contain a few grams of metal, usually a firing pin and its associated spring, setting off a signal in the detector even when a mine is buried or hidden beneath overgrown vegetation.

The bottleneck occurs, however, in discriminating between the few real mines and the many false alarms. Given the wide array of metal objects that can reside in the soil of former battlefields, the false-alarm rate can run as high as 1,000 false positives to one real mine. The result is that the bulk of the searcher's time is spent on the painstaking exposure of harmless metal scraps. And after hundreds of false alarms, the job becomes even more perilous: one surprise mine can maim or kill deminers whose patience has flagged just once, causing them to misjudge the form they uncover. What's more, growing use of plastic-encased mines poses the ominous threat of false negatives: that real mines will remain silent—and deadly—even when swept by a metal detector.

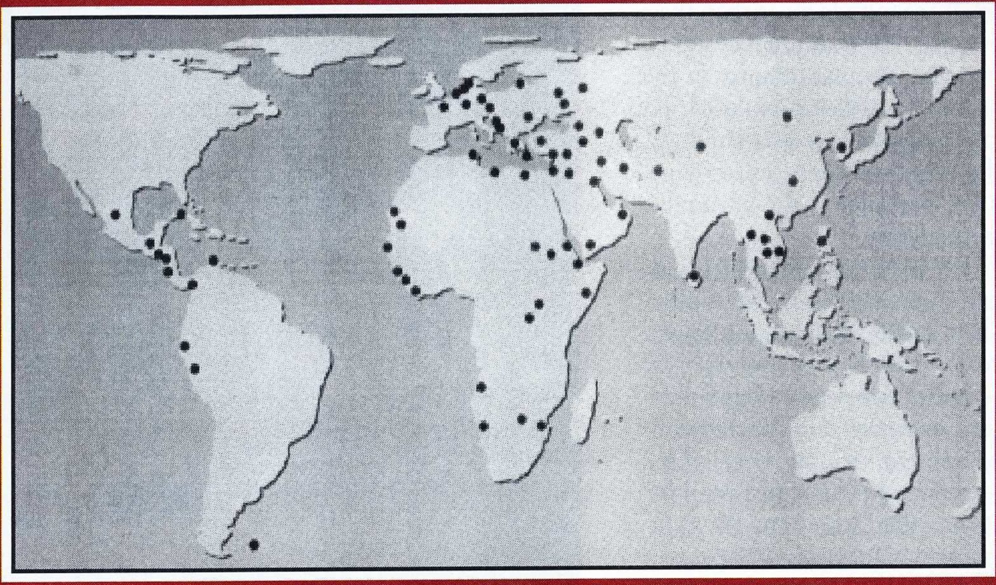
Despite the admittedly grim situation, though, we find some cause for optimism since reviewing the global landmine problem at a week-long meeting last summer. Conducted by the MIT Program in Science and Technology for International Security at the American Academy of Arts and Sciences in Cambridge, Mass., the meeting drew together a disparate group of participants, including a field worker from Laos with many years of demining experience; researchers with expertise in physics, chemistry, electrical engineering, material science, and anthropology; several

PHILIP MORRISON is a physicist and emeritus Institute Professor at MIT. KOSTA TSIPIS directs the Program in Science and Technology for International Security at MIT. Starting this fall, he will head MIT's Humanitarian Demining Project. Both have long worked on arms control issues.





PHOTO ABOVE: DAVID A. FEINGOLD



Among the nations most seriously affected by landmines Afghanistan, Angola, Bosnia-Herzegovina, Cambodia, China, Croatia, Egypt, Eritrea, Iran, Iraq, Somalia, and Sudan each contain more than 1 million mines. These buried weapons kill or maim some 26,000 people worldwide each year.

people working on high-tech mine-detection schemes; and three experts on demining from the military who brought the group a sobering collection of anti-personnel mines (without explosives). Our unexpectedly hopeful view, bolstered by subsequent study, is that while no silver bullet appears to be on the near horizon to solve the demining problem, promising technologies at hand can offer significant help. A number of developing techniques, for instance, detect landmines by sensing physical and chemical properties other than metal content, thereby significantly aiding in the task of reliably discriminating mines from metal scrap. Our analysis indicates that if nations lend enough support, affordable technologies could be available in the field within five years to undertake a humanitarian demining effort on an unprecedented global scale.

A PRIMER ON LANDMINES AND THEIR REMOVAL

Some 700 different models of mines can be found worldwide. Designs differ widely, especially among those mines developed over the past 20 years. The most common landmines are the millions made for use by the militaries of such big powers as the former Soviet Union, China, and the United States and sold around the world. More than a dozen industrialized countries, including Czechoslovakia, France, Italy, and Yugoslavia, have also produced and sold or given away significant numbers of mines.

The major practical distinction among different types of landmines is their intended target. Mines big enough to destroy vehicles are known as anti-tank mines. These mines, roughly the size of large stove-top pots and pans, contain 10 pounds or more of high explosive. Considerably more prevalent, anti-personnel mines are roughly the size of cans of tuna. Containing anywhere from less than an ounce to a half-pound or more of high explosive, they are designed to maim or kill individuals or small groups on foot.

Mines also differ in the cruel cunning of their designs. Sophisticated mines of all sizes may, for instance, incorporate countermeasures against demining. Some, employing an accordion-like trigger design, can withstand the sudden shock of a nearby explosion, detonating only when more slowly depressed, as by the pressure of a foot; others employ anti-disturbance devices that detonate the mine whenever it is handled, injuring or killing would-be deminers. Bounding mines spring up three feet above the ground to shatter into fragments with a lethal radius of 90 feet. And some larger mines may even emit directed fragments: the large U.S. Claymore mine used in Vietnam, for instance, has a 150-foot lethal range for persons walking into its line of fire.

Because the larger-size anti-tank mines cost more to produce and lay, they are much less numerous, increasingly more sophisticated, and generally found on roads or around military installations and other centers of travel and communication. By contrast, anti-personnel mines are cheap, numerous, and prevalent in many diverse locales.

THE 700 OR SO MODELS OF LANDMINES IN USE VARY WIDELY IN SIZE, SHAPE, AND DESIGN, MAKING THE TASK OF FINDING THEM DEVILISHLY DIFFICULT.




PHOTOS OF LANDMINES: DOD

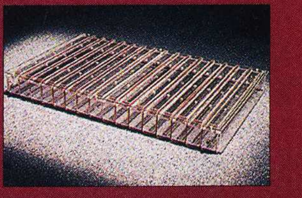
The damage anti-personnel mines inflict—disabling victims for months or for life—is economically worth orders of magnitude more than their cost of a few dollars apiece. By that cruel calculus, they are cost-effective even against irregular infantry or the poorest of unarmed villagers. Because of their prevalence and availability, because they tend to be placed more randomly, and because they make up the bulk of the lingering scourge, these anti-personnel mines are our quarry, the particular focus of humanitarian demining efforts.

To be sure, mines are not new weapons and armies have long developed methods and organizations for demining. But the fact is, today's task of large-scale humanitarian demining is new, and not really open to swift solution by deploying military-trained combat engineers. Humanitarian demining entails peacetime detection and deactivation, over an indefinite period of time, of virtually every mine emplaced in a wide area—a place of home and work to many people whose resources are often scarce and life arduous. Humanitarian demining demands nearly 100 percent detection. The search can be very slow, large numbers of false alarms are acceptable even though costly, and all operations can be confined to good weather and daytime conditions. With these dramatically differing requirements, it is not surprising that demining methods and equipment vary widely.

By contrast, most military demining efforts have favored a capital-costly "brute force" approach that uses motorized vehicles equipped with steel rollers or treads able to detonate anti-personnel mines by riding over them, with damage to the vehicles minimized through clever design and heavy shielding. Some are heavily armored trucks that ride roughshod over mines withstanding most of the anti-personnel detonations with only minor and largely reparable damage. Others, like big bulldozers, attempt to pick up and remove mines, clearing a path as they go.

Such vehicles are particularly suited to so-called military tactical demining which aims to "breach" minefields, rapidly clearing corridors, paths, and roads for combat use even during battle, often within hours. But the brute force approach is largely inappropriate for the highly exacting task of humanitarian demining: when it is applied to uneven ground, it may not detonate every explosive device. Yet such an assurance is precisely what local inhabitants need. The customary test of demining success is direct and public: as the neighborhood watches, the deminers join hands to form a line and walk across the entire plot. Would you yourself settle for less?

Unfortunately, the great variety of fusing mechanisms, of emplacement methods, and of terrain makes the thorough neutralization of anti-personnel mines decidedly difficult. While unquestionably heroic and well suited to the world

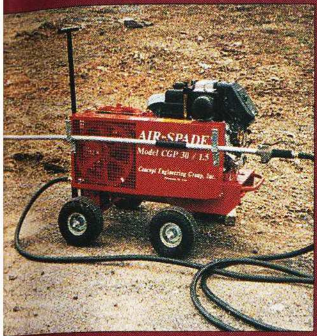


of low technology, the present creep-and-probe method of humanitarian demining is plainly unaffordably slow, expensive, and dangerous. Because of these drawbacks, creep and probe demining as it is currently practiced can have only marginal impact on the global landmine problem. A true solution mandates developing and quickly deploying new methods and equipment that can speed up humanitarian demining by up to a hundred-fold at affordable cost.

IMPROVING CREEP AND PROBE

We believe three currently available technologies, when used together, could offer a 10- to 20-fold improvement over today's demining rate within the next two years. These technologies include detection by a variant of the electronic metal detector (called the meandering winding magnetometer); safe and swift excavation by a device called an air knife; and detonation by a cheap and easily deployed foam-like explosive. All three of these improved demining technologies still require field testing and refinement, but the development tasks look modest.

The basic operating principle of the new meandering winding magnetometer (MWM) detector is the same as that of conventional metal detectors that use a pulsed-electromagnetic induction sensor. But whereas conventional detectors generate an electromagnetic field and sense if it is disturbed by conducting material in their path, MWM detectors generate a varying magnetic field that excites currents in



New technologies to greatly speed the demining process (clockwise from top left): a prototype meandering winding magnetometer for mine detection by Jentek Sensors; Concept Engineering Group's air knife system for exposing mines without detonating them; Lexfoam, a foam-like explosive for safely detonating mines; and the U.S. Army's prototype vehicle-mounted mine detection system, which combines several of these innovations.

metallic objects that align primarily in one direction and can be read by the detector. An MWM detector slightly larger than a conventional metal detector can thus obtain a crude hint of the size and shape of a buried metallic object by combining readouts of these so-called eddy currents. The MWM detector now being developed by Jentek Sensors Inc., of Brighton, Mass., can reportedly determine the rough size, shape, depth of burial, and type of material of the outer shell of a buried metal object. Laboratory evidence indicates that the device can provide enough information for an experienced operator to discern whether a buried object is mere clutter, a mine, or a larger piece of unexploded ordnance.

Field tests of a first-generation MWM prototype indicate that it can lower the false-alarm rate by a factor of 5 to 10 below that of a conventional metal detector. Given such discriminating power, a refined version of such an MWM device could reduce the time spent examining a square meter of scrap-rich ground from 10 to 20 minutes to a fraction of a minute.

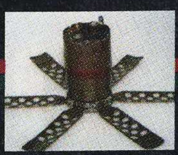
Once a mine is detected, the air knife, now commercially available although not in field-ready form, offers a significant improvement in efficiency and safety over the stick commonly used in today's demining efforts. The air knife blows high-pressure air through a small hand-held probe and can blow away most dirt to expose mines without disturbing them enough to detonate them. Existing air knives are powered by a 3-horsepower gasoline engine, like those that run power lawnmowers, and cost a few thousand dollars. A version adapted for demining could replace the simplest manual probes, greatly speeding up a searcher's ability to expose a mine while improving safety at the same time by obviating the need to dig in the ground with a stick.

The use of the product Lexfoam will also aid demining efforts. The product, much like shaving cream in appearance, is a dilute dispersion of an explosive contained within a foaming plastic substance. Lexfoam is safe and simple to apply and can be set off by an ordinary detonation cap, removing the delicate and hazardous task of wiring a charge onto an unearthed mine. We estimate the use of such a product to blow up the exposed mine would considerably speed up the overall demining process, perhaps by as much as a factor of 2 to 5.

The air knife would require an air compressor (or compressed air supply) carried on a hand-drawn wheeled cart, packaged into a backpack-like portable unit, or built into a small motorized vehicle that carries the MWM metal detector, air knife, and Lexfoam dispenser. In a small, relatively new humanitarian demining unit at Fort Belvoir in Virginia, the U.S. Army is now assembling such a vehicle that combines an MWM detector, compressor, air knife, an operator's plastic shield to protect against explosion, an air-operated weed-cutter, and a Lexfoam dispenser. Col. Harry (Hap) Hambric, who directs development and testing in this unit, estimates that the combined use of these relatively simple technologies where terrain is suitable could speed up demining by a factor of 10 within a year or two, and another factor of 10 with refinements to come.

Just as creep-and-probe methods can find quick technological improvements, though, the brute force demining of open spaces, like field and paddy, can also profit almost at once by the adoption of simple technical improvements. One promising approach proposes to use a small-sized tined roller with hinged spring-loaded prods that can set off anti-personnel mines as it passes over them. The rope-towed (or winched) roller is simple, inexpensive, and easy to repair. It contains hundreds of closely spaced, stiff, spring-mounted fingers able to penetrate up to 25 centimeters into the ground; the roller is towed back and forth across the target area using power supplied by animals or motor vehicles kept at a safe distance.

Tests under controlled conditions performed by the U.S. Army at Fort Belvoir in 1995 proved that the roller was capable of exploding or otherwise destroying small anti-personnel mines even in the mud bottom of rice paddies and other soft floored terrain. A footpath-sized version of the roller also proved to be easily repaired using simple hand tools and hardware. The roller was effective against mines in soft ground and mud. With some design modifications it could be configured to operate on harder surfaces, including areas bearing light foliage.



PHOTOS: DALE SCHLICKER; JOHN M. SCHROEDER/CONCEPT ENGINEERING GROUP, INC.; COMMUNICATIONS AND ELECTRONICS COMMAND NVESD

Thus in certain terrain this technology will allow the welcome option of clearing anti-personnel mines without detecting them first. The Fort Belvoir experts estimate the cost of this multi-pronged roller to be under $20,000, adding that it could drop to as low as $5,000 if the device were mass-produced. The group hopes to field test the system shortly. Taking tools of this sort into the field—even these initial aids imply further improvements—will make a large difference at whatever scale they are put to work. The whole job cannot be finished soon; indeed, a long-lasting culture of understanding and vigilance in the whole countryside, and a reliable source of technical aid from beyond the village—including personnel, equipment, and training—will have to be established in the most affected countries. Determination to keep up and extend the good work will thrive if visible progress comes soon in one or two places.

A half-dozen affluent nations could share the cost of demining by devoting a tiny fraction of their military budgets.

HIGH-TECH DETECTION

While near-term technological improvements offer hope for better demining efficiency, technologies undergoing vigorous research and development for use against airline terrorism offer even more promise for the future. Portable, rugged versions of these technologies, which detect small amounts of explosives, would be required for use in demining, but the task is certainly not beyond the capabilities of high-tech firms in the United States and elsewhere.

These technologies could take advantage of the fact that landmines use characteristic materials in well-defined shapes and sizes, giving them mechanical, acoustic, electromagnetic, and nuclear absorption and reflection properties potentially detectable from a modest distance. All mines contain high explosives, substances otherwise rare in the soil, and are thus open to many means of detection based on their chemical composition.

Such chemical sensing is perhaps the most advanced of

these avenues. Since all mines contain 10 grams or more of explosives, one way to avoid the time-consuming step of discriminating mines from false alarms, and to detect plastic as well as metallic mines, is to devise detectors sensitive to the presence of explosives, either in their condensed or vapor phase. We know that mines carry traces of their explosives because dogs trained to scent high explosives can detect buried mines under field conditions in a short time, with a 95 percent success rate and a false alarm rate of around two to one. Unfortunately, though, dogs tire easily and are expensive to train and keep. Arrays of sensors, each with some specificity to a particular molecule or compound, are quite commonly used in the food and perfume industries to identify products' constituent compounds. The U.S. Defense Advanced Research Projects Agency is actively pursuing an array of such sensors intended for explosives detection at airports that could well be adaptable for humanitarian demining.

One detector already in trial use at airports pulls an air sample through to a collector that transfers any minute traces of explosives to a separation device. There, an instrument called a high-speed gas chromatograph separates explosives from one another and from non-explosive compounds by the length of time it takes each compound to go through the instrument. Each compound yields a reliable and characteristic signature. Noting both this signature time and its amplitude, the detector can determine the type of explosive and the level of its concentration in the air sample. The manufacturer, Thermetics Detection based in Woburn, Mass., claims that its system can detect the presence of 10 to 20 picograms of TNT—a grain twice the size of a speck of dust—with a thousand times the sensitivity of a dog. The system is capable of detecting picogram levels of explosives in less than a minute, and has worked well in the presence of potentially interfering compounds in the air or the soil.

Company representatives believe that a single portable, battery-powered detector could detect mines with greater than 90 percent accuracy while scanning ten square yards per minute. What is not known yet is to what degree high-explosive vapor and particles deposited by past weapons firing in the areas where mines are buried might generate an unmanageably high level of background noise. Detailed field measurements at the sites of past combat, as well as of background levels in battle-free and mine-free areas, must be conducted before the practicality of this potential mine detector can be fully determined.

At least two other technologies could potentially be used to detect mines by sensing their main charges. The first is based on nuclear quadrupole resonance (NQR), an electrostatic relative of magnetic resonance imaging now familiar in the medical world. NQR is an effect displayed by atomic

PHOTO ABOVE LEFT: DAVID A. FEINGOLD

Toward a Global Ban on Landmines

BY SEN. PATRICK LEAHY

FIVE years ago almost no one was aware of the landmine problem, except mine victims and the volunteers and agencies who cared for them. That began to change when former President Bush signed into law legislation I wrote to stop U.S. exports of anti-personnel mines. Since then, most other mine-exporting countries have followed our example, and many have gone further by banning the production and use of anti-personnel mines. Some governments are already destroying their stocks of landmines.

Last December, the General Assembly of the United Nations voted 156 to 0, with 10 abstentions, to vigorously pursue an international treaty banning anti-personnel mines. This September, at the initiative of the Canadian government, negotiators in Oslo, Norway, are hammering out a treaty to be signed in Ottawa in December, when representatives from some 100 countries are expected to attend. After five short years, the world is on the verge of an agreement to ban these weapons.

Yet although the United States initiated this effort, we have since fallen behind. Until recently, the Clinton administration had agreed to negotiate a treaty to ban landmines only through the U.N. Conference on Disarmament The president's decision in August to also join the Ottawa process is a hopeful sign that reinvigorated U.S. leadership toward a ban may still be possible in the months ahead. The problem with the Conference on Disarmament process is that any single participant can block a landmine ban indefinitely. That seemingly has suited the White House fine: it has stated that the United States will not stop producing and using anti-personnel landmines until China and Russia do the same.

Ironically, the administration took the opposite position on the Chemical Weapons Convention. Even though several countries that produce chemical weapons refused to sign that treaty, the United States did sign. As Defense Secretary William Cohen put it, "The Chemical Weapons Convention will reduce the chemical weapons problem to a few notorious rogues." What the Clinton administration seems not to grasp is that the same could be said of a reasonable agreement to ban anti-personnel landmines, which have killed or maimed far more innocent civilians than chemical weapons have.

SENATOR LEAHY RECEIVES PETITIONS URGING THE U.S. TO LEAD NEGOTIATIONS THIS FALL THAT WOULD FINALIZE A GLOBAL TREATY OUTLAWING LANDMINES.

Clearly, a more promising course is the Canadian initiative. Common sense suggests that a treaty setting a new international norm and having 50 to 100 or more signatories is far preferable to no treaty at all, as the administration argued so effectively on the chemical weapons issue. If the United States were to renounce its own use of anti-personnel mines, as have many of our NATO allies and the governments of other countries where landmines have produced devastating effects, we would instantly become the world's leader in the push to finalize such a ban. Unfortunately, the administration, after standing aside from the Ottawa process until now, is entering these negotiations with a list of Pentagon demands for broad exceptions. I am hopeful that the White House ultimately will think better of those demands and instead assume the leadership role in these talks that is fitting of the world's lone military superpower.

But while a ban is urgently needed, it alone cannot solve the landmine problem. As one Cambodian told me, citizens of that country clear their mines "an arm and a leg at a time." A ban will do nothing to eliminate the 100 million landmines already in the ground in some 68 countries, each one waiting to explode from the pressure of a footstep. We must continue to invest in improved demining technology. The effort has begun through the Defense Department's Humanitarian Demining Technologies Program, which this year received $14 million to undertake R&D on demining technologies and fund private companies to do the same.

As new technologies that can significantly reduce the time, cost, and danger of demining come within our reach, the program will require our continued and growing support. And we must also do more to aid the victims of landmine accidents. The Leahy War Victims Fund is a start, awarding $5 million annually to the victims who have paid so dearly for the world's use of a weapon that our own Gen. William Tecumseh Sherman, more than a century and a half ago, called a violation of civilized warfare. ■

PATRICK LEAHY, Democratic Senator from Vermont, is a longtime congressional leader on efforts to ban landmines. He is the ranking Democrat on the Foreign Operations Subcommittee of the Senate Appropriations Committee.

nuclei that are not spherically symmetrical but slightly squashed or elongated at the poles. Nitrogen atoms, a near-universal primary ingredient of high explosives, possess just such nuclear asymmetry. Depending on what kind of crystalline structure the nitrogen nuclei find themselves in, their non-sphericity produces a unique set of very narrowly spaced energy levels that is characteristic of the crystalline solid itself. An explosive compound can therefore be identified by the subtle resonance of its constituent nitrogen atoms.

NQR detectors have already been tested in airports, where they have managed, within six seconds, to detect the military explosive RDX in quantities comparable to those in a mine. Tests at the Naval Research Laboratory based in Alexandria, Va., have shown that NQR detectors, unaffected by soil contaminants like metals and magnets, can reliably discern explosives from other nitrogenous materials in the soil such as fertilizer or living organisms. A field NQR detector would operate much like a hand-held metal detector but would require a backpack to accommodate its larger battery. NQR commercial developer Quantum Magnetics of San Diego estimates that a prototype mine detector based on NQR could be developed within two years at a cost of about $1 million. The price of such detectors, once produced in quantities of several thousand, they believe, would probably be under $10,000 each—some two to three times more than the cost of high-quality metal detectors. With an adequate level of development funding, it is quite possible that NQR could become an effective tool for discriminating mines from metal clutter within 3 to 5 years, reducing the false alarm rate to negligible levels.

The technology does pose some difficulties at present, however. The dominant obstacle is the efficient detection of TNT, the explosive ingredient of 80 percent of landmines. TNT has an intrinsically weak NQR signal, requiring a longer integration time in the detector. An NQR mine detector that had to linger over each spot on the ground for minutes at a time would clearly be too slow, although it could still presumably prove useful in distinguishing mines from scrap metal.

A second way to detect plastic mines by their explosive content is to "illuminate" the ground with a beam of low-energy x-rays. Because of the difference in their average atomic numbers, soil will absorb low-energy x-rays impinging upon it, while the lighter mine will "backscatter" a large fraction of the incoming radiation. When imaged, the mine thus appears as a luminous spot on a dark background of soil. Experiments conducted as early as 1975 by the U.S. Army Mobility Equipment Research and Development Center showed that, while awkward, clumsy, and dangerous at the time, the method does in fact work, unambiguously detecting small (six centimeters in diameter) plastic mines buried under two centimeters of soil.

Although x-ray backscattering detectors perform well in detecting explosives and other materials with low atomic numbers at airports and customs stations, they have shortcomings for detecting plastic mines: they cannot reliably discriminate explosives from other materials with similar atomic numbers (such as roots and water), they detect only shallow-buried mines, and they require an intense source of ionizing radiation that could cause health hazards to the operator. A hand-held detector may therefore not prove practical, but x-ray backscattering detectors might eventually be used on remotely controlled demining vehicles to detect plastic mines in conjunction with a metal detector such as the meandering winding magnetometer.

LAUNCHING A GLOBAL DEMINING CAMPAIGN

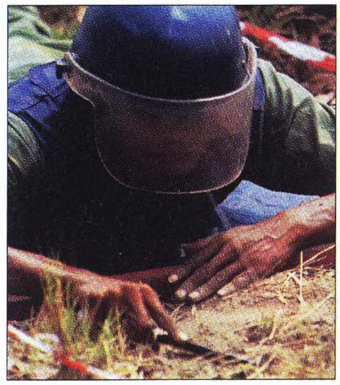
To make humanitarian demining feasible on a large scale, the demining rate must greatly increase to reduce overall costs and justify expenditures for more sophisticated equipment. This will require a gradual shift from a labor-intensive low-tech approach to the intermediate stage of introducing power tools and discriminating detectors. The final stage will require the development of autonomous, mechanized demining systems to incorporate some of the more sophisticated detection technologies we have described. Such progress will require a coherent, sustained, and adequately supported R&D effort in the range of tens of millions of dollars annually over several years.

Unfortunately, frustration with the marginal results of even the most heroic demining efforts so far has led to a tired indifference among the public and decision makers alike. This frustration has, in turn, led to the loss of opportunities for new solutions. The constellation of humanitarian relief organizations that have patiently shouldered most of the demining efforts, including the Red Cross, CARE, and the United Nations, to name just a few, have had little contact with the scientific and technical communities in academia and in high-tech industries that could boost demining efficiency. For their part, the scientific and technical communities in the developed world have largely ignored the problem. As an example of this lack of technological partnership, a one-million-pound reward offered several years ago by the British Government for an acceptable plan to demine the remote and difficult terrain of the Falkland Islands has gone unclaimed.

One antidote to such indifference could be visible progress in several key locations. And some such progress might be easily attainable. For example, an impressive test of the MWM could be performed in Laos. During the Vietnam War, U.S. aircraft dropped millions of cluster bomblets on

the country, but many did not explode and now lie scattered practically everywhere: in villages and fields, schoolyards, next to the passenger lounge at a regional airport. Since the Laos bomblets were made in the United States, our military knows their characteristic size, shape, and metallic skin, so that detecting them with an MWM would be straightforward.

If we assume that 10 percent of the total area of Laos requires clearance, 1,000 deminers employing traditional creep-and-probe techniques would take roughly 25 years to accomplish the task, at a cost of about $200 million. On the other hand, if efficient technology like the MWM could reduce the demining rate by a factor of five within the next five years—which seems entirely likely—the overall cost could be closer to $50 million. Such a trial could go far to establishing the feasibility of large-scale humanitarian demining with a new generation of equipment.



Advances in demining technology can also help augment airport security and boost U.S. manufacturers.

What makes such a scenario all the more feasible is that awareness of the scale of the demining problem is now gaining among decisionmakers and the public alike in the developed world. Thanks to the unstinting effort of Senator Patrick Leahy (D-Vt.; *see "Toward a Global Ban on Landmines," page 45*), U.S. funding for research and development of humanitarian demining devices has recently become available. The United States expects to spend some $45 million between 1995 and 1999. As a result, the Army's humanitarian demining team of roughly 30 to 40 personnel at Fort Belvoir has been able to continue developing and testing a number of useful demining systems, and government funding is helping similar R&D efforts at high-tech companies and universities. Meanwhile, the European Union nations began just this year to budget sums roughly comparable to the U.S. funding levels for research and development on humanitarian demining technologies.

The magnitude and complexity of humanitarian demining is so large, however, that its goals cannot be achieved by earnest, even ingenious, efforts as long as they remain uncoordinated. Progress in humanitarian demining will require both technical development for a few years and the organization of field operations later on. The nature and scale of the effort is reminiscent of the successful task of eliminating smallpox worldwide undertaken by the World Health Organization in the mid-1960s. We envision a coherent, systematic, international program that can begin with measurements of physical and chemical properties of mines, guide the development and field testing of demining equipment, and spur production and distribution of the equipment to users around the world. The training of operators will require a parallel effort as will the creation of a central Internet database on demining research.

The cost of actual demining is difficult to calculate exactly, but the cost of neutralization per mine now varies between $200 (in Cambodia) and $400 (in Kuwait), and we aim at an order of magnitude reduction to $20 to $40 per mine 5 years from now. If we assume an average cost of $30 per mine and a goal of neutralizing 75 percent of existing landmines in 25 years, the total cost will be $2.25 billion—or less than $100 million per year. This amount could be shared by half a dozen affluent nations who devoted a minor fraction of their military budgets.

Perhaps the governments of Canada or Sweden would be candidates to manage the program. Canada, for instance, helped coordinate the initiative that led to the agreement by 68 countries, including the United States, Russia, and China, to curb the deployment of landmines, and has expressed interest in taking the initiative on demining. With the strong leadership of such a nation, we imagine a flexible international collaborative effort with a minimum of diplomatic formalities.

None of that will be possible, however, without stable, long-term, adequate funding by many developed nations. Both President Clinton and Vice-President Gore have indicated their interest in the issue and might lend their support once they see the effort as practical. Not only would such support generate worldwide awareness of U.S. leadership for the common good, but it could help foster technological advances that could benefit military demining, augment airport security, and boost U.S. exports.

Such practical benefits aside, we firmly believe a global humanitarian demining campaign would receive widespread public support simply because it is clearly the right thing to do. How can we not act to abate this grimly lethal pollution, a residue of twentieth-century war-making, still growing and grievously wounding countless children and adults in many lands? ■

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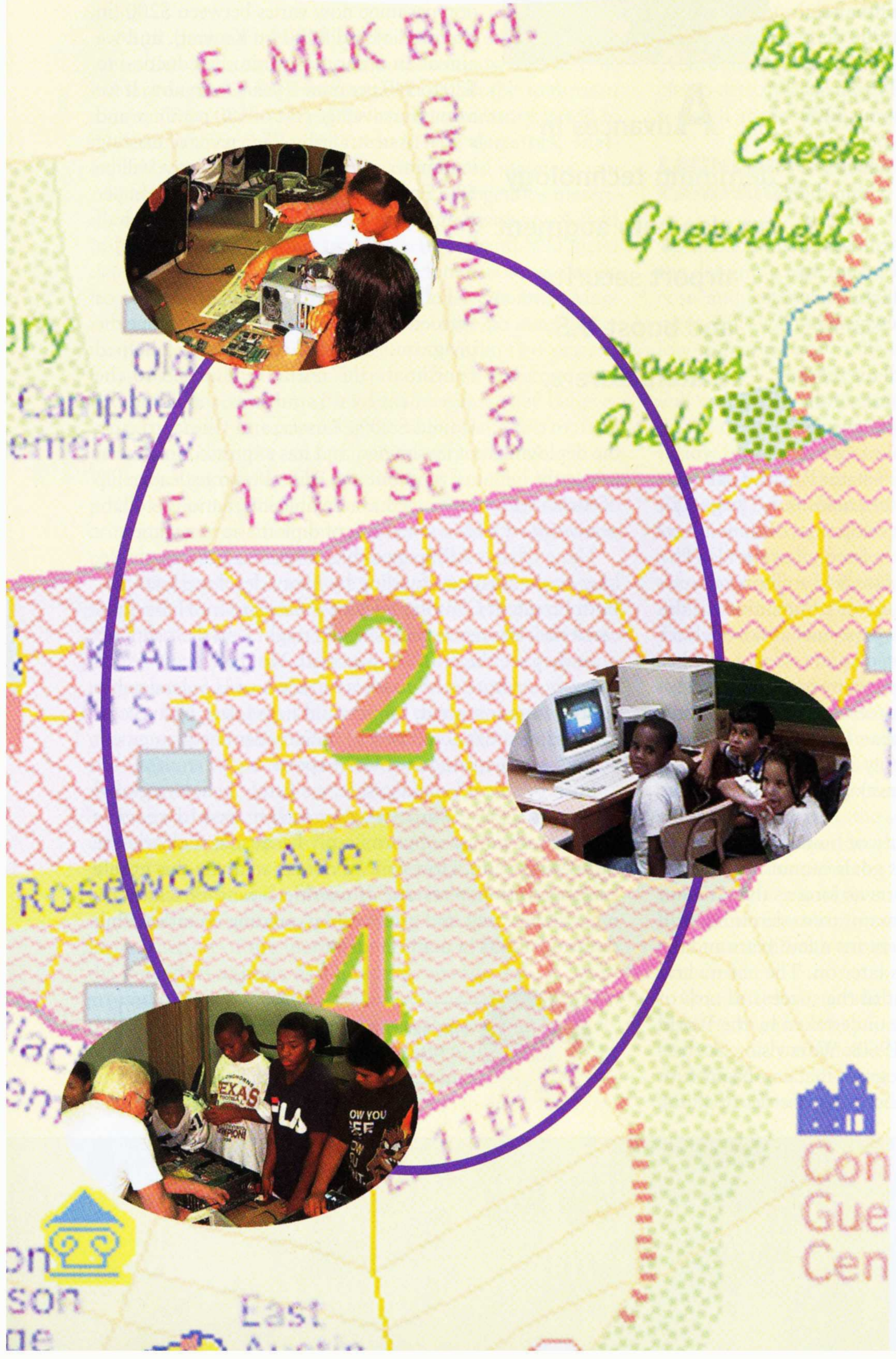

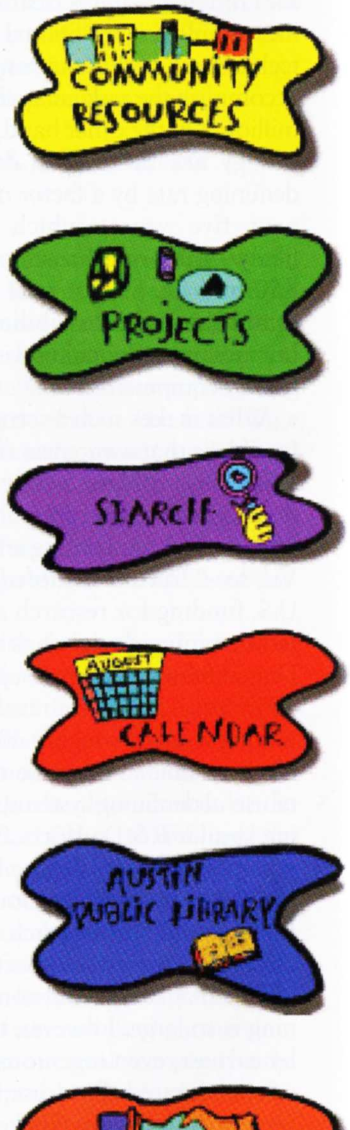

hborhood Nets

By Gary Chapman and Lodis Rhodes

Providing free access to computer networking can extend the pleasures and benefits of the Net to people living in poor communities.

Timika Mitchell was living in the Salvation Army shelter in Austin, Tex., when she developed her first home page on the World Wide Web. A homeless person with an Internet home page may seem to represent a scrambling of priorities. But for Mitchell—an unmarried mother of two—her home page is a source of pride and, she hopes, an entry point into the high-tech economy. Thanks in part to her abilities to create on the Web, this tall, talkative, self-directed young African-American woman landed a job with Time Warner, moved into her own apartment—and created a second Web page, where she plans to publish her poetry.

PHOTOS: AUSTIN FREE-NET

Austin boasts one of the highest per capita rates of Internet use in the world and has recently been cited as the nation's fastest growing job market. On the west side of town lies one of the world's leading high-tech centers, with major semiconductor manufacturing firms, a booming new media industry, and tens of thousands of computer professionals. But Mitchell lives in East Austin—a poverty zone segregated from the rest of Austin by an interstate highway. In her neighborhood, known as the 11th and 12th Streets Corridor, the median annual income is $6,000 per year. The area suffers from high unemployment, poor schools, drugs, gangs, and violence.

Computers are still clearly beyond the means of most such low-income citizens, and will be for many years, even if prices decline significantly. WebTV, a new service recently acquired by Microsoft, provides access to the Web and e-mail over TV sets, but its access fee of about $30 per month is too high for most poor families, as is the $200 box required to use it. When Newt Gingrich briefly posed the idea of tax credits for poor people who buy computers, he was widely ridiculed and quickly dropped the idea. ("Let Them Eat Laptops," one headline read.) Such a scheme would be hugely expensive; Michael Kinsley noted in the *New Yorker* that subsidizing poor Americans' purchases of $1,000 computers would cost the U.S. Treasury $40 billion.

The disparities in access to the Internet in the United States are well documented. Computers are present in almost half of urban households with incomes over $35,000 per year, according to a survey last year by the National Telecommunications and Information Administration. By contrast, only 8 percent of households with incomes less than $10,000 have a computer. Most of the Internet users in low-income brackets are students, who typically have connections through their schools. In Austin and other high-tech communities, the disparity in computer ownership between rich and poor is even more pronounced.

But communities and leaders throughout the United States are beginning to come to grips with the growing gap between the poor and the affluent in their access to information technology. Since most well-paying jobs now demand computer skills and a rising number require familiarity with the Internet, consensus is growing that access to the Internet is as important a part of civic life as parks, public transit, libraries, and cultural centers. In a dramatic testament to this point of view, Microsoft chairman Bill Gates recently announced that he will donate $200 million to U.S. public libraries to expand such facilities.

One way to bridge the gulf between computer haves and have-nots is to provide Internet connections through publicly accessible terminals. In this spirit, for the past three years we have been exploring how to bring the Internet and computer skills to the low-income, largely minority community of East Austin. An operation called Austin Free-Net installed and maintains public access computers throughout the city. In cooperation with the nonprofit Austin Learning Academy, teachers and volunteers are striving to link the Internet to the real-world experiences of Americans whose circumstances and backgrounds differ substantially from the typical Internet-using population. We're finding that community-based computer networking, accessible through public-access terminals, is a cost-effective way to introduce information technologies to low-income neighborhoods and to engage their citizens in using them.

The Austin Free-Net is part of a nationwide movement, known as "community networks." More than 200 such networks are running in the United States, according to Douglas Schuler, author of *New Community Networks: Wired for Change.* Some community networks receive modest grants from local governments or, in a few instances, from the federal government. These efforts are shoestring operations, often staffed by volunteers and using donated equipment and telephone lines.

Timika Mitchell (near left) created her Web home page while homeless. Using the Web, she found the Victory Grill (top), where she performs her poetry. Etta Kelly (right), a 22-year-old mother of 4, now shows other mothers how to use the Net. A community policing effort based at the Ebenezer Church (bottom) is looking to strengthen its community ties through the network.

Building Real (Not Virtual) Community

Cyberspace is full of "virtual communities"—groups of people linked by common interests. You're as likely to exchange views with someone in Australia as with a person living down the street. Austin Free-Net and similar computer networks foster the old-fashioned kind of community—that is, a group of people defined fundamentally by physical proximity.

One big problem with the early community networks is that they did not actually represent communities in any tangible sense—they were typically just a cheap way for people to get online. When the cost of Internet access plum-

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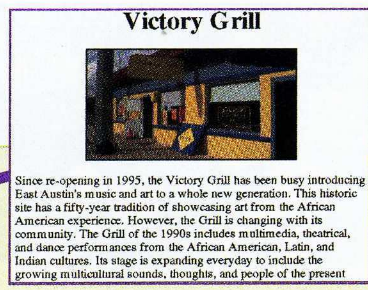
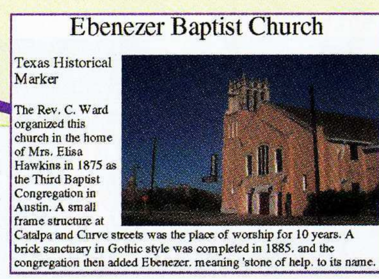
meted, that rationale evaporated for many customers; nonprofit community networks could no longer compete. Moreover, even community networks that developed locally oriented resources, such as online car pools, directories, and political information, wound up appealing primarily to people already online who manage to find their way to the community network and then decide to linger.

The concept of geographic community is often much stronger and more tangible in low-income areas than in more affluent locales. Poor people spend more time in their own neighborhoods because they are less mobile, and the economic boundaries of such places are often their most distinctive feature. In such communities, the Net would best serve to help cement the bonds that already exist, rather than to link individuals to a vast, faraway marketplace.





A community network can enhance the efforts of residents already grappling with the myriad problems in poor neighborhoods. Senior citizens in East Austin, for example, are starting to explore how to use Austin Free-Net to stay in touch with one another. Area churches are beginning to offer computer classes, and their members are developing Web pages that provide a guide to church-related activities. Through the work of the Austin Learning Academy, mothers taking classes leading to high-school diplomas are learning how to use computers, as are their children in after-school programs—strengthening both literacy skills and family bonds.

The benefits of the Free-Net in East Austin are particularly apparent among young people. Explains Jay de la Garza, a 14-year-old computer whiz: "My parents wouldn't let me out at night because it's dangerous where we live. There are drug dealers and criminals. But they let me go to Free-Net sites to do what I love to do most, which is help teach people the Internet." Jay has been accepted to a school for gifted students, and works for Free-Net as a volunteer.

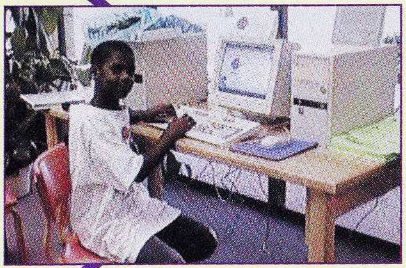
One problem with encouraging low-income users to explore the Internet is that few resources on the Net come from urban ghettos, poor rural communities, or other places familiar to low-income rural and urban users. Despite the rhetoric about shedding labels of gender, race, and social class upon entering cyberspace, the Internet reflects the culture of its principal inhabitants—upper middle-class white males. Thus the global network is dominated by the culture, tastes, preoccupations, styles, and interests of the affluent. A network isn't much good if you don't know anybody who has e-mail; an online shopping mall holds little allure to someone lacking money and credit cards.

Thus the organizers of the Austin Free-Net are seeking to lay a virtual environment over real geographic places, to supplement existing connections between people, institutions, and programs with electronic ones. We are producing a web of network links and communication patterns that resemble those one finds in the community already. This approach gives community leaders a reason to use the technology, apart from mere curiosity. Free-Net terminals are being introduced into community police centers, recreation centers, public housing projects, job training centers, and church facilities; the latter includes a new training center for multimedia housed in a building owned by Austin's oldest Catholic church, Our Lady of Guadalupe. A Free-Net volunteer, Harry Williams, a lay minister and engineer, and his wife Marilyn began a computer lab in their church, New Lincoln Baptist. These computers help nearby citizens learn to use the technology.

Residents of East Austin identified key community assets such as training centers, churches, schools, performing arts centers, recreation centers, and nonprofit organizations, and created an online database of people, programs, calendars, and events. This "Neighborhood Net" database re-creates—in electronic form, on a Web page—the networking that already exists in the community. The Web page includes a map that shows the physical layout of the com-

munity's resources and provides links to other pages with additional information. Eventually, this online database may become a unique encyclopedia of information about the neighborhood.

The Austin Police Department is exploring the use of the community network to strengthen the links between police officers and neighborhood associations, nonprofit groups, and public housing managers, to enhance community policing tactics. Ricky Davis, an Austin Police officer who staffs the community police center at Ebenezer Baptist Church, says he gets between 400 and 600 calls per month requesting information. For example, he says, "people who want to move into a particular apartment want to know the crime statistics for that building. I have to look up the address on a map, then look up the area in our quarterly crime statistics report, which is a big notebook." Davis recommends putting this information on a Web page accessible to everyone.



Davis would also like the network to allow residents to report abandoned vehicles, drug houses, broken lights and windows, and other problems, to enable the department to enhance its community policing efforts. "We're trying to move beyond responding to individual complaints to anticipating problems," Davis says. "But to do that we really need a thorough knowledge of the community, and we can't develop that by ourselves—people in the community have to be involved. The Free-Net could be a big help."

Links between the online and off-line worlds can help connect people and organizations who would otherwise not interact. Timika Mitchell, for example, uses the network to discover how to make a name for herself as a poet. Mitchell looked at a Web-page map of East Austin and came upon a picture and description of the Victory Grill, a historic African-American performing arts theater and cafe. She has since visited the Grill and arranged to read her work there. Mitchell is now part of a network of local artists.

Demand Deficits and Learning Curves

Our approach to developing network infrastructure and skills emphasizes building and deepening the skills of the community as a whole, as well as the skills of individual users. In Austin, we focus on "training trainers"; we offer people instruction in Internet publishing, for instance, with the proviso that they must then dedicate time to helping teach others. This summer, teenagers who enrolled in a "build your own computer" class were required as part of the curriculum to introduce computers to a friend. This approach emphasizes informal, ongoing, social learning.

Most people who spend time in cyberspace—up to 70 percent of users, according to some surveys—access the Net primarily at work or at school. Their use of the network has a certain purpose. People in low-income communities, however, typically don't encounter the Internet either at school or at work, and they must discover their own reasons to use this technology, as well as a place to use it. Thus the problem of a "demand deficit" is common in poor communities.

Users in East Austin typically issue vague pronouncements that they are learning the Internet for their kids, "who need to know this stuff." Another common theme reveals a desire simply not to be left behind. Says Timika Mitchell: "Everywhere you turn, it's www.com this, or www.com that." Young people have seen Web addresses in television ads, such as for Nike shoes or Hollywood movies, or have heard their peers discuss chat groups or online games.

Helen Hart—a lifelong resident of East Austin who has lived in the same house for 60 years—is typical in this respect. Hart worked as a crossing guard at a nearby elementary school for 12 years and is active in her neighborhood association. She encountered the Internet for the first time in her neighborhood library at a public-access computer terminal installed and run by the volunteers of Austin Free-Net. Her encounters with the World Wide Web have

done nothing to dislodge her initial belief that the Internet, and computers in general, have little value for her life.

But others in East Austin have found computer networking to be an uplifting experience. Etta Kelly, 22, had her first child at age 14 and lives in one of East Austin's public housing developments. Her ambition is to go to college and get a degree in business. She and her four children participate in the Austin Learning Academy's Even Start program, which helps her study for her General Education Degree. With the help of some students at the University of Texas, Etta developed a Web page about herself, describing her life, her children, and her hopes, and featuring a photo of her family. At a recent parenting conference hosted by the university, Etta sat at a table with a computer hooked to the Internet, showing other mothers her Web page and answering questions about how to find other information on the Internet, clearly proud of her presence in cyberspace.

As more low-income citizens are introduced to the Internet, they are using the medium for a greater variety of purposes. Austin Free-Net, for example, recently sponsored a "key pal" session of women from public housing in Austin talking to their counterparts in South Africa and sharing experiences. One Austin woman was so excited about this project that she couldn't sleep the night before; she has now dedicated herself to keeping the communication going.

Using computers placed in libraries and other public spaces, low-income residents of East Austin can go online to get information about events in their community.

The learning curve for new users in poor communities has a distinct arc, characterized by three stages that we've witnessed countless times:

1. *"I Can Do This."*

In the first stage a novice discovers that simply using the technology is not that difficult, and that basic skills like manipulating the mouse and keyboard produce nearly instant results. The Web's point-and-click interface has made quick competence with the Internet possible, and search engines on the Web make finding online information or interesting sites much easier than what was required two or three years ago. Because of the sheer volume of material on the Web, nearly everyone can find something of interest, be it gardening, sports, cooking, games, chat rooms, or information about government benefits.

2. *"Look at This."*

The user quickly finds an item of personal interest that he or she wants to share with someone else. The sharing indicates a pride of accomplishment and a new level of confidence. Perhaps more important, this stage marks the realization that the Net is more than just an information bank but also a communications tool.

3. *"There Ought to Be a Way."*

Users also quickly realize that they should be able to find information of personal significance and relevance—or even to produce information that might be interesting to others. During one of our first training sessions two years ago, East Austin was facing a controversial school bond vote. Not far into the training, we were asked if the Web contained information on the issue. It did, and our trainees devised a strategy to look for it.

At this point, the problem often becomes one of how to harness the new users' enthusiasm. Unfortunately, Free-Net volunteers are so busy just trying to get computers up and running, and then training people in the basics, that they don't always have time to follow through in ways that the users want. In the case of the school bond, for example, the question arose: "How do we tell people what we think of this school bond?" But the election happened before opponents from the East side of town organized themselves into using the Free-Net to present their views.

Lesson of Public Access

An important lesson about how to foster effective public access to the network revolves around where to put public-access computers. Most community networks still tend to site their terminals in schools and libraries. But our experience shows that it is better to locate public access computers not in the quiet solitude of libraries but in venues in which people in low-income communities tend to gather informally during the course of their daily lives. What's more, many libraries do not permit patrons to develop their own Web pages or to upload files to Internet servers; librarians tend to view the Internet as a reference tool, not a means for personal publishing. We've had success locating terminals in churches, recreation centers, and local businesses, and hope to put additional computers in cafes, laundromats, alternative schools, youth centers, shopping centers, and even bars and sports facilities. After all, the skills required for using the Internet are acquired by sharing experiences with others, and in a social atmosphere.

Regardless of where the terminals are situated, users need to be able to put their own information on Internet servers.

10 COMMUNITY NETWORKS

NETWORK	AREA SERVED	WEB SITE	DISTINCTIVE CHARACTERISTICS
ACEnet	rural southeastern Ohio	www.seorf.ohiou.edu/~xx001	Participant in Public Webmarket—an attempt to help local entrepreneurs, artists, and craftspeople sell goods and services on the Internet
Charlotte's Web	Charlotte, North Carolina	www.charweb.org	Serves 10,000 users; provides training and computers to community organizations; developed low-cost touch-screen kiosks
Greater New Orleans Free-Net	New Orleans	www.gnofn.org	Targets low-income neighborhoods in partnership with U.S. Department of Housing and Urban Development; 16,000 users
Hill House Community Access Network	Pittsburgh	www.hillhouse.ckp.edu/hhcan	Offers 20 community access sites along with e-mail accounts
LibertyNet	Philadelphia	www.libertynet.org:80	Features eight public-access computer centers plus a truck with laptops and cellular modems
LincolnNet	South Metro Chicago	www.lincolnnet.net	Youth "Web cast" called CyberSight, for low-income students
Mountain Area Information Network	Western North Carolina	www.main.nc.us	Computer recycling program for the disabled; provides no-cost training for low-income users
NeighborTech	inner city Chicago	www.iit.edu/~nnet	Grassroots group founded by low-income residents and organizations; sponsors twice-yearly technology fair
Ohio Community Computing Center Network	Akron, Columbus, Dayton, Marietta, Toledo, and Youngstown	www.ctcnet.org/occcn.html	Targets low-income neighborhoods; centers are collaborations among community organizations
Tri-Cities Free-Net	Columbia River Basin, Oregon and Washington	www.tcfn.org	Community technology centers for low-income citizens and the disabled

But this generally requires that users have access to a server's file structure—an ability that system administrators are wary of providing. Some community networks are therefore beginning to experiment with software tools that will allow people to create Web pages in "protected" areas of a server and that do not require sophisticated programming. The City of Austin, for example, has developed software that allows nonexpert users to create Web pages without knowing hypertext markup language or how to load Web pages onto a server; pushing a button automatically inserts all the necessary codes to format the text, create hyperlinks, and deposit the page into the right space on the server's hard disk. This system may enable local nonprofits and neighborhood associations to maintain Web sites without assistance from a system administrator or an expert Web page developer.

An even more urgent need is for software that makes it practical for community networks to offer the one service that has more than any other wedded people to the Net: electronic mail. Neither the Austin Free-Net nor many other community networks offer e-mail. The costs of constantly creating new accounts, eliminating dormant ones, and managing "bounced" mail are beyond the means of volunteer-run networks. In the commercial world, e-mail accounts are usually made available to people who are part of a relatively stable group, such as a university community or corporation, or to customers who pay by the month or year. There are no precedents for people using e-mail on a pure "pay-per-use" basis akin to the purchase of postage stamps.

Millions of people are reportedly using free e-mail accounts provided by HotMail, a company that derives revenue by selling advertisements that users see each time they access their account. Unfortunately, HotMail suffers from a fundamental security flaw: hitting the "back" key on the browser has brought to the screen the mail written and received by previous users of the same terminal, presenting a significant privacy concern. HotMail has announced a new feature in its service—a "logout" button that will clear the mail from a public access terminal—that, if it works the way the company promises, will solve this problem.

Much work remains to tailor the software and hardware of public-access stations to accommodate users who cannot afford personal computers or Internet accounts. We are confident that the computer profession can come up with solutions; whether those will develop into a profitable market remains to be seen, but in the meantime, we can hope that skilled programmers and responsible companies view this task as a public service to the nation. ■

TR ONLINE

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Recycling Is not Garbage

Critics trash recycling as unnecessary, expensive, and too much bother. But these conclusions are garbage, say two leading advocates, because they are based on ideology rather than a practical understanding of how recycling works.

BY RICHARD A. DENISON AND JOHN F. RUSTON

PHOTOS: SCHLOWSKY

Ever since the inception of recycling, opponents have insisted that ordinary citizens would never take the time to sort recyclable items from their trash. But despite such dour predictions, household recycling has flourished. From 1988 to 1996, the number of municipal curbside recycling collection programs climbed from about 1,000 to 8,817, according to *BioCycle* magazine. Such programs now serve 51 percent of the population. Facilities for composting yard trimmings grew from about 700 to 3,260 over the same period. These efforts complement more than 9,000 recycling drop-off centers and tens of thousands of workplace collection programs. According to the EPA, the nation recycled or composted 27 percent of its municipal solid waste in 1995, up from 9.6 percent in 1980.

Depsite these trends, a number of think tanks, including the Competitive Enterprise Institute and the Cato Institute (both in Washington, D.C.), the Reason Foundation (in Santa Monica, Calif.), and the Waste Policy Center (in Leesburg, Va.), have jumped on the anti-recycling bandwagon. These organizations are funded in part by companies in the packaging, consumer products, and waste-management industries, who fear consumers' scrutiny of the environmental impacts of their products. The anti-recyclers maintain that government bureaucrats have imposed recycling on people against their will—conjuring up an image of Big Brother hiding behind every recycling bin. Yet several consumer researchers, such as the Rowland Company in New York, have found that recycling enjoys strong support because people believe it is good for the environment and conserves resources, not because of government edict.

RICHARD A. DENISON is a senior scientist and JOHN F. RUSTON is an economic analyst with the Environmental Defense Fund in Washington, D.C. and New York City, respectively.

Alas, the debate over recycling rages on. The most prominent example was an article that appeared last year in the *New York Times Magazine,* titled "Recycling Is Garbage," whose author, John Tierney, relied primarily on information supplied by groups ideologically opposed to recycling. Here we address the myths he and other recycling opponents promote.

The modern recycling movement is the product of a false crisis in landfill space created by the media and environmentalists. There is no shortage of places to put our trash.

Fact: Recycling is much more than an alternative to landfills. The so-called landfill crisis of the late 1980s undoubtedly lent some impetus to the recycling movement (although in many cities around the country, recycling gained momentum as an alternative to incineration, not landfills). The issues underlying the landfill crisis, however, were more about cost than space.

Landfill space is a commodity whose price varies from time to time and from place to place. Not surprisingly, prices tend to be highest in areas where population density is high and land is expensive. In the second half of the 1980s, as environmental regulations became more stringent, large numbers of old landfills began to close, and many simply filled up, particularly in the Northeast. New landfills had to meet the tougher standards; as a result, landfill prices in these regions escalated dramatically. In parts of northern New Jersey, for example, towns that shifted their garbage disposal from local dumps to out-of-state landfills found that disposal costs shot from $15-20 per ton of garbage to more than $100 per ton in a single year. Although the number of open landfills in the United States declined dramatically—according to *BioCycle* magazine, from about 8,000 in 1988 to fewer than 3,100 in 1995—huge, regional landfills located in areas where land is cheap ultimately replaced many small, unregulated town dumps. Landfill fees declined somewhat and the predicted crisis was averted. Nonetheless, the high costs of waste disposal in the Northeast and, to a lesser extent, the West Coast, have spurred local interest in recycling: two-thirds of the nation's curbside recycling programs operate in these regions.

But landfills are only part of the picture. The more important goals of recycling are to reduce environmental damage

from activities such as strip mining and clearcutting (used to extract virgin raw materials) and to conserve energy, reduce pollution, and minimize solid waste in manufacturing new products. Several recent major studies have compared the lifecycle environmental impacts of the recycled materials system (collecting and processing recyclable materials and manufacturing them into usable form) with that of the virgin materials system (extracting virgin resources, refining and manufacturing them into usable materials, and disposing of waste through landfills or incineration). Materials included in the studies are those typically collected in curbside programs (newspaper, corrugated cardboard, office paper, magazines, paper packaging, aluminum and steel cans, glass bottles, and certain types of plastic bottles). The studies were conducted by Argonne National Labs, the Department of Energy and Stanford Research Institute, the Sound Resource Management Group, Franklin Associates, Ltd., and the Tellus Institute. All of the studies found that recycling-based systems provide substantial environmental advantages over virgin materials systems: because material collected for recycling has already been refined and processed, it requires less energy, produces fewer common air and water pollutants, and generates substantially less solid waste. In all, these studies confirm what advocates of recycling have long claimed: that recycling is an environmentally beneficial alternative to the extraction and manufacture of virgin materials, not just an alternative to landfills.

Recycling is not necessary because landfilling trash is environmentally safe.

Fact: Landfills are major sources of air and water pollution, including greenhouse gas emissions.

According to "Recycling Is Garbage," municipal solid waste landfills contain small amounts of hazardous lead and mercury, but studies have found that these poisons stay trapped inside the mass of garbage even in the old unlined dumps that were built before today's stringent regulations. But this statement is simply wrong. In fact, 250 out of 1,204 toxic waste sites on the Environmental Protection Agency's Superfund National Priority List are former municipal solid waste landfills. And a lot more than just lead and mercury goes into—and comes out of—ordinary landfills. The leachate that drains from municipal landfills is remarkably similar to that draining from hazardous waste landfills in both composition and concentration of pollutants. While most modern landfills include systems that collect some or all of this leachate, these systems are absent from older facilities that are still operating. Moreover, even when landfill design prevents leachate from escaping and contaminating groundwater, the collected leachate must be treated and then discharged. This imposes a major expense and burden on already encumbered plants that also treat municipal sewage.

What's more, decomposing paper, yard waste, and other materials in landfills produce a variety of harmful gaseous emissions, including volatile organic chemicals, which add to urban smog, and methane, a greenhouse gas that contributes to global warming. Only a small minority of landfills operating today collect these gases; as of 1995, the EPA estimates, only 17 percent of trash was disposed of in landfills equipped with gas-collection systems. According to a 1996 study by the EPA, landfills give off an estimated 36 percent of all methane emissions in the United States. We estimate that methane emissions from landfills in the United States are 24 percent lower than they would be if recycling were discontinued.

Recycling is not cost effective. It should pay for itself.

Fact: We do not expect landfills or incinerators to pay for themselves, nor should we expect this of recycling. No other form of waste disposal, or even waste collection, pays for itself. Waste management is simply a cost society must bear.

Unlike the alternatives, recycling is much more than just another form of solid waste management. Nonetheless, setting aside the environmental benefits, let's approach the issue as accountants. The real question communities must face is whether adding recycling to a traditional waste-management system will increase the overall cost of the system over the long term. The answer, in large part, depends on the design and maturity of the recycling program and the rate of participation within the community.

Taking a snapshot of recycling costs at a single moment early in the life of community programs is misleading. For one thing, prices of recyclable materials fluctuate, so that an accurate estimate of revenues emerges only over time. For

another, costs tend to decline as programs mature and expand. Most early curbside recycling collection programs were inherently inefficient because they duplicated existing trash-collection systems. Often two trucks and crews drove down the same streets every week to collect the same amount of material that one truck used to handle. Many U.S. cities have since made their recycling collection systems more cost-effective by changing truck designs, collection schedules, and truck routes in response to the fact that picking up recyclable refuse and yard trimmings leaves less trash for garbage trucks to collect. For example, Visalia, Calif., has developed a truck that collects refuse and recyclable materials simultaneously. And Fayetteville, Ark., added curbside recycling with no increase in residential bills by cutting back waste collection from twice weekly to once.

Several major cities—Seattle, San Jose, Austin, Cincinnati, Green Bay, and Portland, Ore.—have calculated that their per-ton recycling costs are lower than per-ton garbage collection and disposal. In part, these results may reflect the overall rate of recycling: a study of recycling costs in 60 randomly selected U.S. cities by the Ecodata consulting firm in Westport, Conn., found that in cities with comparatively high levels of recycling, per-ton recycling collection costs were much lower than in cities with low recycling rates. A similar survey of 15 North Carolina cites and counties conducted by the North Carolina Department of Environment, Health, and Natural Resources found that in municipalities with recycling rates greater than 12 percent, the per-ton cost of recycling was lower than that for trash disposal. Higher rates allow cities to use equipment more efficiently and generate greater revenues to offset collection costs. If we factor in increased sales of recyclable materials and reductions in landfill disposal costs, many of these high-recycling cities may break even or make money from recycling, especially in years when prices are high.

Seattle, for example, has achieved a 39 percent recycling/composting collection rate in its residential curbside program and a 44 percent collection rate citywide. Analysis of nine years of detailed data collected by the Seattle Solid Waste Utility shows that, after a two-year startup period, recycling services saved the city's solid waste management program \$1.7 to \$2.8 million per year. These savings occurred during a period of reduced market prices for recyclable materials; the city's landfill fees, meanwhile, are slightly above the national average. In 1995, when prices for recyclable materials were higher, Seattle's recycling program generated savings of approximately \$7 million in a total budget of \$29 million for all residential solid waste management services.

To reduce the cost of recycling programs, U.S. communities need to boost recycling rates. A study of 500 towns and cities by Skumatz Economic Research Associates in Seattle, Wash., found that the single most powerful tool in boosting recycling is to charge households for the trash they don't recycle. This step raised recycling levels by 8 to 10 percent on average. These kinds of variable-rate programs are now in place in more than 2,800 communities, compared with virtually none a decade ago.

Recycled materials are worthless; there is no viable market for them.

Fact: While the prices of recycled materials fluctuate over time like those of any other commodity, the volume of major scrap materials sold in domestic and global markets is growing steadily. Moreover, many robust manufacturing industries in the United States already rely on recycled materials. These businesses are an important part of our economy and provide the market foundation for the entire recycling process.

In paper manufacturing, for example, new mills that recycle paper to make corrugated boxes, newsprint, commercial tissue products, and folding cartons generally have lower capital and operating costs than new mills using virgin wood, because the work of separating cellulose fibers from wood has already occurred. Manufacturers of office paper may also face favorable economics when using recycling to expand their mills. Overall, since 1989, the use of recycled fiber by U.S. paper manufacturers has been growing faster than the use of virgin fiber. By 1995, 34 percent of the fiber used by U.S. papermakers was recycled, compared with 23 percent a decade earlier. During the 1990s, U.S. pulp and paper manufacturers began to build or expand more than 50 recycled paper mills, at a projected cost of more than \$10 billion.

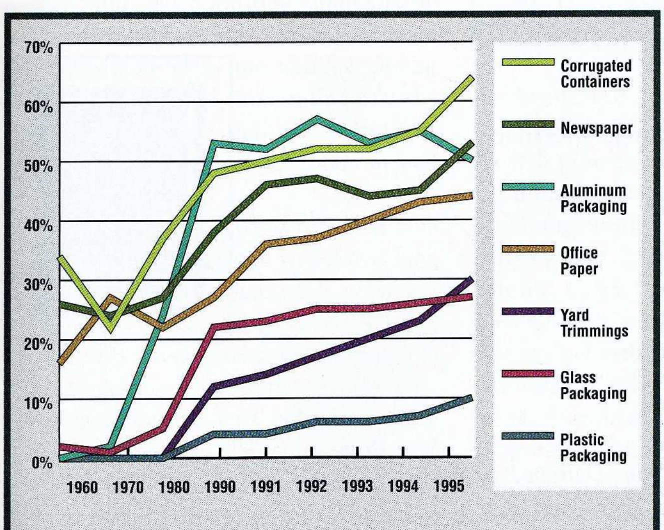
Recycling has long been the lower-cost manufacturing option for aluminum smelters; and it is essential to the scrap-fired steel "mini-mills" that are part of the rebirth of a competitive U.S. steel industry. The plastics industry, however, continues to invest in virgin petrochemical plants rather than recycling infrastructure—one of several reasons why the market for recycled plastics remains limited. Another factor not addressed by the plastics industry is that

many consumer products come in different types of plastic that look alike but are more difficult to recycle when mixed together. Makers and users of plastic—unlike those of glass, aluminum, steel, and paper—have yet to work together to design for recyclability.

Recycling doesn't "save trees" because we are growing at least as many trees as we cut to make paper.

Fact: Growing trees on plantations has contributed to a severe and continuing loss of natural forests.

In the southern United States, for example, where most of the trees used to make paper are grown, the proportion of pine forest in plantations has risen from 2.5 percent in 1950 to more than 40 percent in 1990, with a concomitant loss of natural pine forest. At this rate, the acreage of pine plantations will overtake the area of natural pine forests in the South during this decade, and is projected to approach 70 percent of all pine forests in the country during the next few decades. While pine plantations are excellent for growing wood, they are far less suited than natural forests to providing animal habitat and preserving biodiversity. By extending the overall fiber supply, paper recycling can help reduce the pressure to convert remaining natural forests to tree farms.



RECYCLING RATES FOR MUNICIPAL SOLID WASTE
(percent of total waste recycled)

Recycling rates have risen dramatically over nearly four decades. Yet much potential remains, particularly for plastic materials, whose makers and users have yet to work together to design for recyclability.

Recycling becomes even more important when we view paper consumption and wood-fiber supply from a global perspective. Since 1982, the majority of the growth in worldwide paper production has been supported by recycled fiber, much of it from the United States. According to one projection, demand for paper in Asia, which does not have the extensive wood resources of North America or northern Europe, will grow from 60 million tons in 1990 to 107 million tons in 2000. To forestall intense pressures on forests in areas such as Indonesia and Malaysia, industry analysts say that recycling will have to increase, a prediction that concurs with U.S. Forest Service projections.

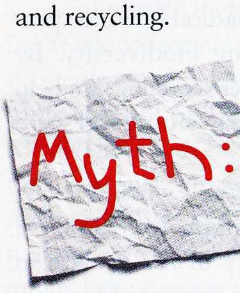
Consumers needn't be concerned about recycling when they make purchasing decisions, since stringent U.S. regulations ensure that products' prices incorporate the costs of the environmental harms they may cause. Buying the lowest-priced products, rather than recycling, is the best way to reduce environmental impacts.

Fact: Even the most regulated industries generate a range of environmental damages, or "externalities," that are not reflected in market prices.

When a coastal wetland in the Carolinas is converted to a pine plantation, estuarine fish hatcheries and water quality may decline but the market price of wood will not reflect this hidden cost. Similarly, a can of motor oil does not cost more to a buyer who plans to dispose of it by pouring it into the gutter, potentially contaminating groundwater or surface water, than to a buyer who plans to dispose of it properly. And there is simply no way to assign a meaningful economic value to rare animal or plant species, such as those endangered by clearcutting or strip mining to extract virgin resources. While many products made from recycled materials are competitive in price and function with virgin

GRAPH: ENVIRONMENTAL DEFENSE FUND

products, buying the cheapest products available does not provide an environmental substitute for waste reduction and recycling.



Recycling imposes a time-consuming burden on the American public.

Fact: Convenient, well-designed recycling programs allow Americans to take simple actions in their daily lives to reduce the environmental impact of the products they consume.

In a bizarre example of research, the author of "Recycling Is Garbage" asked a college student in New York City to measure the time he spent separating materials for recycling during one week. The total came to eight minutes. The author calculated that participation in recycling cost the student $2,000 per ton of recyclable trash by factoring in janitors wages and the rent for a square foot of kitchen space, as if dropping the newspapers on the way out the door could be equated with going to work as a janitor, or as if New Yorkers had the means to turn small, unused increments of apartment floor space into tradable commodities.

Using this logic, the author might have taken the next step of calculating the economic cost to society when the college student makes his bed and does his dishes every day. The only difference between recycling and other routine housework, like taking out the trash, is that one makes your immediate environment cleaner while the other does the same for the broader environment. Sorting trash does take some extra effort, although most people find it less of a hassle than sorting mail, according to one consumer survey. More important, it provides a simple, inexpensive way for people to reduce the environmental impact of the products they consume.

If we are serious about lowering the costs of recycling, the best approach is to study carefully how different communities improve efficiency and increase participation rates—not to engage in debating-club arguments with little relevance to the real-world problems these communities face. By boosting the efficiency of municipal recycling, establishing clear price incentives where we can, and capitalizing on the full range of environmental and industrial benefits of recycling, we can bring recycling much closer to its full potential.

Life in the Fast Growth Lane

With information technology finally yielding productivity gains, now is not the time to shy away from public spending.

BENNETT HARRISON

THE recent successes of the American economy have surpassed everyone's expectations. We've managed to combine fast economic growth, low unemployment, and virtually nonexistent inflation. How did these happy conditions come about? What has technology got to do with it? And what policies can keep the ball rolling?

On the last question, conventional wisdom is insistent in its answer: slash government spending, weaken job security in the name of "flexibility," and keep Wall Street happy and private business will take it from there. Technology, according to this view, is not a major factor. A different school of thought, however, asserts that technology plays a central role in today's noninflationary growth. Whether our growth spurt will turn into a new long wave of prosperity turns on getting this right.

The key question is: how fast can the economy grow without triggering inflation? Official Clinton administration forecasts, and overcautious mainstream economists such as MIT's Paul Krugman, continue to preach on the need for "diminished expectations," contending that the U.S. gross domestic product cannot grow sustainably at an annual pace of more than about 2.3 percent.

They are wrong. This is not your parents' GDP. The forces that were for so long assumed to trigger inflationary pressures have weakened or disappeared. Global competition, along with the undeniable (and regrettable) weakening of the bargaining power of unions, hold down price and wage growth. The successful "oil war" against Iraq has stabilized energy prices. The number of people wanting to work, and the hours of paid employment they are seeking, are at record highs and rising; the labor shortages that presaged earlier rounds of inflation are nowhere on the horizon. Most important, the long-promised productivity improvements from the use of computers and electronic communications are finally spreading throughout American business, from banking to retail trade to carmaking.

Based on these shifts, University of Massachusetts-Boston economist Barry Bluestone and I estimate that the long-run rate of potential annual economic growth now exceeds 3.0 percent. Over the next decade, that seven-tenths of a percentage point difference between 3.0 percent and 2.3 percent growth will amount to $3.1 *trillion* worth of GDP. Allowing the economy's growth to fall that far behind its potential will cost us millions of jobs, numerous improvements in public health, and significant progress in combating urban poverty. Yet such underachievement will be precisely the consequence of cutting government spending on infrastructure and R&D.

Pathbreaking ideas about the relationship between short-run public policy, technology, investment, and long-term growth make excessive caution even more socially costly and therefore intolerable. Businesses respond to signals from policymakers as to whether overall demand—the key to future sales—is likely to grow. If policymakers keep short-run growth systematically beneath its potential by, for example, gutting public spending, companies will spend less on new plant and equipment. The recent spurt of investment is largely a catching-up after years of neglect; without positive expectations of future growth in demand, this investment cannot last. What we will lose if we neglect the situation are the innovations and productivity benefits that bubble up from investments in technology, which have a way of spilling over into unanticipated applications. In short, not only does technology contribute to growth, but the expectation of growth increases companies' willingness to invest in new technology.

The U.S. economy's performance is inspiring the world. At a conference this summer in Rome attended by trade union leaders, government ministers, and economists from all over Europe, I heard one official after another express wonder at our robust growth even as they decried the dark side of U.S. economic expansion (one conference participant rightly bemoaned our "chronic inequities" and stagnating U.S. wages). An emerging growth consensus in Europe calls for sensible but targeted government spending on R&D, training, and infrastructure. Such public investments will not only provide jobs and useful services now, but also send signals to business about the likely payoffs to their own investments in technology that are the key to tomorrow's economic growth.

Public spending is not the whole story, of course. Private investment in technology is unlikely to fully pay off unless business managers make their operations more hospitable to networking and collaboration. And companies need to devote more resources to training their ordinary employees, not just their highest-paid professionals. But without more expansionary national economic policies, we will continue to sabotage the prospect for achieving even greater prosperity than what we are momentarily enjoying.■

BENNETT HARRISON teaches economics and urban policy at the New School for Social Research in New York. He and Barry Bluestone are completing a book on how technology can accelerate long-run economic growth.

PHOTO: L. BARRY HETHERINGTON

CONTINUED FROM PAGE 8

The amazing part is that the Ehrlichs and their colleagues have lost no credibility with the press and television by being wrong. Instead, they are lionized and as much-quoted as ever. No further research is needed to discredit their assertions and speculations. Explaining their continuing influence is a research task that still needs doing—one that will require the skills of a social psychologist and those of a media analyst who examines the behavior of the newspapers and television stations.

JULIAN L. SIMON
College of Business and Management
University of Maryland at College Park
College Park, Md.

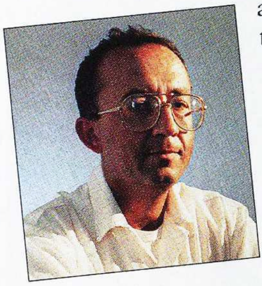
AN INVENTOR FIGHTS FOR OWNERSHIP

If Seth Shulman accurately sets forth the facts concerning the Taborsky case in "A Researcher's Conviction" (*Trends, TR February/March 1997*), then I hope the efforts to restore Taborsky's rights to his inventions and to reverse his criminal conviction succeed.

As a long-time patent examiner and attorney, I can attest that the University of South Florida and possibly also the company that sponsored the research do have shop rights to Taborsky's invention because he used their equipment and resources. This does not, however, make them the owners. A shop right merely gives individuals, universities, or companies the right to use an invention in their own facilities. Even a confidentiality agreement (according to the article, all parties are agreed that there was none in the Taborsky case) would not convey ownership. At best, it would have prevented Taborsky from disclosing the invention.

What is extremely disturbing is that both the university and the company apparently believe that they are entitled to all rights and that the inventor was entitled to no royalties. The fact that a student is being paid for doing research should not mean that he or she should be forced to turn over an invention without any recompense. And Leonard Minks's quip that "undergraduates simply aren't supposed to invent things" is utter nonsense. The youngest person to receive a U.S. patent filed the application at the age of seven!

The fact that the company agreed to name Taborsky as the primary author on its patent application reflects only the requirement under U.S. patent law—the company apparently gave Taborsky only what they were legally required to give him.



Shulman writes, "Despite the intervention of the university and of Carnahan (the university laboratory manager), who claimed to be the invention's owner, the Patent Office held that Taborsky *was* the rightful inventor and awarded him a patent in 1992." No italics were needed to stress the decision because the Patent Office decides inventorship, not ownership. The latter is the crux of this case.

ALVIN GUTTAG
Gaithersburg, Md

INVENTIONS ABOUND

"Unlocking the Legacies of Edison Archives" (*TR February/March 1997*) by Seth Shulman was very interesting. I was reminded, however, that Edison's work has often eclipsed the achievements of other inventors. For example, while Edison invented the phonograph, my grandfather, Emile Berliner, invented the lateral groove record, which offered much better fidelity than Edison's records. Another of my grandfather's inventions was the loose-contact microphone, whose patent was purchased by Alexander Graham Bell. I know of other inventors who worked on microphones but, despite Shulman's claim, Edison was not among them.

RICHARD H. SANDERS
Orlando, Fla.

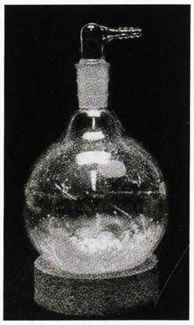
I wonder if Shulman's statement that Edison chose tungsten as the best material for the phonograph needle might have resulted from confusion with the lightbulb filament, which is definitely made of tungsten. Tungsten would have been okay for the needle, but ruby, sapphire, and diamond were already known for their resistance to abrasive wear and for their abilities to accept a very smooth and nondurable surface finish.

ROALD CANN
Springfield, Vt.

Editor's note:
Leonard DeGraff of the Edison Archives confirmed that Edison used gems to make needles for his phonographs. DeGraff noted, however, that he could not rule out the possibility that Edison experimented with tungsten needles.

THE BEAUTY OF SCIENCE

Having observed firsthand Catherine Wagner's exhibition "Art and Science," I was particularly happy to see her photographs featured in "An Artist Explores the Lab" (*TR April 1997*). At first, I was put off, or at least perplexed, by the lack of any human figures in the photographs. The stark, "lifeless" quality could be seen as a stereotype of science and its supposedly detached, unhuman nature. But what Wagner portrays is the means of the production of science, much as photographers have recorded agricultural work through still lifes of farm machinery, equipment, and buildings without their users or occupants. The lifeless quality is only temporary—it is important to view the objects as poised for use. Wagner's photographs represent an imaginative and innovative way of depicting science that is seldom seen in our high-tech society. Congratulations to both Wagner and *Technology Review* for this interesting and illuminating portrayal.



GARLAND E. ALLEN
Professor of Biology
Washington University
St. Louis, Mo.

Campaigns, Commercials, and Computers

Technology shoulders some of the blame for today's corrupt campaign-financing practices. Newer technology might help fix it.

SAMUEL C. FLORMAN

THE other day, as I was reading yet another cautionary op-ed essay about campaign financing, it occurred to me that when it comes to politics, engineers are pretty virtuous folk. Then, scarcely a moment later, with a sudden pang of guilt, I thought: Yes, but if it weren't for engineers, we wouldn't be in such a mess in the first place.

Engineers are mostly law-abiding professionals, little involved with politics, dismayed by the escalating scandal of fundraising and elections. The major professional societies are, in IRS parlance, 501(c)(3) corporations, committed to "charitable," "scientific," or "educational" purposes, and so are forbidden to engage in partisan political activities. Such societies may not give money to candidates for political office, and they are restricted in how much of their budgets they can devote to lobbying on behalf of issues. The few engineering organizations that are classified instead as "business leagues," and thus are permitted to establish political action committees, raise less than $10 per member—well within the bounds of propriety. Last year, for example, the National Society of Professional Engineers's PAC raised about $80,000 from the society's 63,000 members, and gave support to 87 "pro-engineering" candidates nationwide—politicians who favor strong government support for R&D, science education, renewing infrastructure, and cleaning up the environment. What's good for engineering appears to be good for the nation.

But to what avail is engineering morality when we are told that the campaign-finance crisis stems from technological progress, which in turn results from engineering endeavors? In the world of election campaigns, it is television that has made all the difference. Although the medium has been crucial to the election of every president since JFK, political TV commercials have proved to be more potent than anyone guessed they would be. Money has always been a central element in politics, but television amplifies to an alarming degree the ability to translate money into votes. Historical examples abound of engineering advances producing unanticipated consequences, and here we have one that is truly distressing.

While technology lies at the root of the problem, technology might also provide a remedy. The day after last November's election, the governor of Wisconsin, responding to public outcry over outrageous campaign tactics, appointed a bipartisan commission to recommend improvements in the election law. The panel concluded that the campaign-financing process is broken not only because TV advertising is so expensive and thus requires fundraising that often skirts the law, but also because voters have no ready way to find out who is contributing to whose campaigns. The process is invisible and unaccountable, and the system of regulation is "seriously strained." By law, candidates must disclose information on contributions and expenditures, but this information remains difficult to decipher—for regulators, the press, political rivals, and particularly the public. In Texas, for instance, anyone wanting to look at a candidate's list of contributors must travel to Austin—a 3-hour drive from Dallas, 10 hours from El Paso—and wade through stacks of paper.

Thus the key to fundamental reform of campaign financing, according to the Wisconsin commission, is to establish a coherent system of public disclosure. Yes, giving limits need to be reviewed, as does the loophole of "soft money"—funds raised by political parties outside the control of campaign regulations. But the biggest impact will occur if states set up computer databases that will simplify the task of finding up-to-date records of contributions and spending. Such a system exists in Washington State, where candidates must periodically file complete reports electronically. The state posts these financial disclosures on the Internet. The director of the Citizens' Research Foundation at the University of Southern California hails the Washington State approach as "a model." Other states, including Maryland and Kentucky, are moving toward similarly sophisticated systems.

And there we have it. Public disclosure of campaign records, kept up to date and available to everyone who has access to a computer—this is the technological fix needed to counter the technological hazard. The transgressions wrought by television are to be redeemed by the computer. Will such measures prove effective? Some knowledgeable people seem to think so. Of course, technical ingenuity alone will not completely resolve the crisis. Moral commitment is also required, and here, by maintaining high standards in their own political activity, engineers can also serve.■

SAMUEL C. FLORMAN (scf97@aol.com), a civil engineer, is the author of The Existential Pleasures of Engineering, *recently reissued in a new edition. His latest book is* The Introspective Engineer.

PHOTO: L. BARRY HETHERINGTON

Reviews

BOOKS

MAPS WITHOUT DIRECTION

Cartographies of Danger: Mapping Hazards in America
by Mark Monmonier
University of Chicago Press, $25

BY ARNOLD BARNETT

WE all know that the risks we face depend not just on who we are but *where* we are. California is the most earthquake-prone state in the continental United States but, even within California, the hazard is far from uniform. San Diego is at scant danger compared with the San Francisco Bay area, for example. And within the Bay area itself, your fate during an earthquake depends on the type of structure you're in and whether tectonic convulsions can liquify the ground beneath you.

"Wouldn't it be nice," asks Mark Monmonier in the preface to *Cartographies of Danger*, "to have no-go, no-build, or no-live maps for all kinds of nasty surprises?" He answers his own question with a book full of well-presented maps. Those maps presented the author with an immediate danger—namely, that by the third chapter, the readers would start skimming at high speed. Fortunately, thanks to Monmonier's lucid and stimulating narrative, I never had such a reaction.

The author makes clear early on that cartography is essential for discussing how physical hazards correlate with geography. Only a small number of the risks we face actually do show such a correlation, however. Part of why the book stays interesting is that, with the author's subtle help, we realize that some maps that claim to delineate hazards could actually do more harm than good.

Even though some maps appear to provide important information, on closer inspection they provide the reader with nothing useful. Consider "Estimated Potential for Contamination of the Intermediate Aquifer System in Polk County, Florida," which divides the county into three parts based on a low, moderate, or high degree of hazard. I have no idea what health risks, if any, arise from such contamination; nor am I aware of why it seemed prudent to speak of three discrete categories of risk rather than two or a continuous measure of risk.

Similarly, maps that pinpoint the

locations of recent crimes imply that they can tell us where we cannot go safely. But the value of such information is questionable. In large cities, for example, the local police allocate patrols according to these maps. If drug deals are known to occur on a certain street, the police may increase their presence there. This may, however, prompt the dealers to move to another less-policed street. Moreover, sheer counts of the number of crimes at various places may be poor proxies for actual risk levels. Consider New York's Central Park, where few people venture after dark. If no one enters the park at night and the police therefore record no nocturnal muggings, it does not follow that I can stroll there safely at midnight.

We must also be cautious in interpreting maps that claim to link health risks with geography. Monmonier observes, "In real epidemiology, maps often raise more questions than they answer." Consider a map on age-adjusted coronary death rates for white males. If the rate is unusually high in northern Florida, for example, that circumstance does not necessarily indicate lethal spinoffs from the Daytona speedway. Rather, it might reflect high-cholesterol diets in the region, in which case a "lean-cuisine" eater who moves to the area would be totally unaffected by the overall statistics. The geographic pattern, in other words, might be the starting point for analysis of a risk that ultimately has nothing to do with geography per se. The associated map might be helpful but viewers had better beware of making spurious inferences that "geography is destiny."

Readers should also be wary of maps that extrapolate geographic tendencies from rare occurrences in nature. In a "threat rating" map by the National Oceanic and Atmospheric Administration based on 17 years of tornado data, Massachusetts ranks as the most dangerous state with a score of 347 while adjacent Rhode Island is assigned a score of zero. But concluding that Massachusetts residents can escape tornado dangers by crossing the (utterly flat) border to Rhode Island is obviously absurd. What drives the reported pattern is one tragic tornado that struck the Worcester area four decades ago. If the tornado had touched down a few dozen miles further south near Providence, R.I., the threat ratings would have been turned upside down.

By the end of this book, we reach an unexpected conclusion: we must handle maps about hazards with care, for a substantial number are potentially misleading as guides to where we should go. The adage that a picture is worth a thousand words may be true here in a perverse way: before we use a cartography of danger as a basis for restricting our movements, we had better read about what the map purports to show. Of all the reasons to restrict our movement, sheer geography may be among the weakest. ■

ARNOLD BARNETT, a professor of operations research at MIT's Sloan School of Management, specializes in applied statistics.

ILLUSTRATIONS: TODD GRAVELINE

BOOKS

BIAS IN SCIENCE?

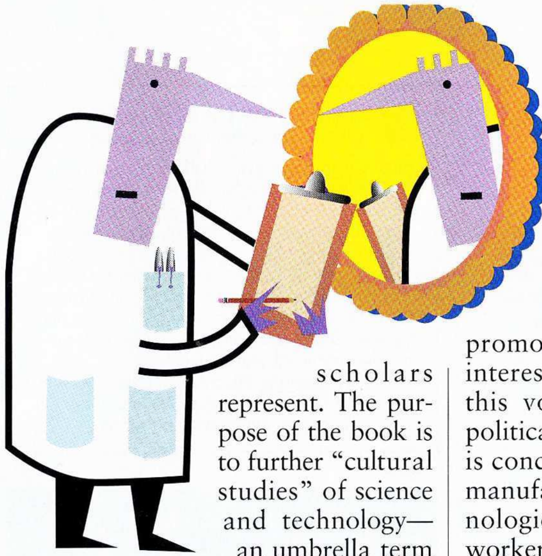
Technoscience and Cyberculture
by Stanley Aronowitz, Barbara Martinson, Michael Menser, and Jennifer Rich, eds.
Routledge, $18.95

BY BRYAN C. TAYLOR

THIS volume comes in the wake of a stinging practical joke that brought many of the professional tensions between scientists and humanists into sharp relief. One of the editors, sociologist Stanley Aronowitz, and one of the contributors, literary scholar Andrew Ross, coedited a 1996 issue of the academic journal *Social Text* that was devoted to "postmodern" studies of science—contemporary scholarly work that emphasizes the influence of cultural values and institutional politics on science. That special issue featured an essay by physicist Alan Sokal, who, in discussing a "transformative hermeneutics of quantum gravity," expressed the critically fashionable view that scientific knowledge is often not truly rational, and that claims of scientific objectivity can mask pursuit of the interests of dominant groups.

The problem was that after the issue was published, Sokal revealed his article as a hoax—a satire of postmodernism fabricated out of bits of jargon. Both the mainstream media and hostile scientists framed the journal's failure to reject the piece as an indictment of contemporary humanists. The editors' ignorance of real scientific knowledge rendered them incapable of distinguishing spoof from substance, the argument ran.

Technoscience and Cyberculture, edited by Stanley Aronowitz along with three graduate students in sociology (Barbara Martinson), philosophy (Michael Menser), and English (Jennifer Rich), is evidence that the charge has not entirely fazed the community these



scholars represent. The purpose of the book is to further "cultural studies" of science and technology—an umbrella term for a range of postmodern scholarly efforts that focus on how specific aspects of everyday life are shaped by larger social, economic, and political influences. While the essays included are diverse, representing 11 fields of study, they are united in their conviction that, Sokal notwithstanding, scientific knowledge is saturated with cultural assumptions.

Proponents of cultural studies argue that technology is commonly developed and used by powerful interests to maintain control over social conditions. Thus the critic's job is to point out the values and beliefs that drive technological systems, and to suggest ways to keep those forces from dominating people's lives. In this book, for example, experimental architect Lebbeus Woods describes how the design of "anarchic" spaces can compensate for the control of public space by political authorities and commercial developers. The idea would be to allow citizens to circulate free from both surveillance and the compulsion to consume.

The field of cultural studies also recognizes that technological systems often do more to determine our sense of reality than we realize. For instance, two chapters of *Technoscience and Cyberculture* clarify how optical-sensing technologies create images that sustain the mythologies of the groups that design those technologies. According to humanities scholar Jody Berland, one such technology is the weather satellite, whose "celestial" images show landscapes without borders. By bridging Canada's regional factionalism, these images sustain the fantasy of a unified identity for that nation.

The language designers and promoters use to frame technology interests the scholars represented in this volume as well. For example, political scientist Arthur Kroker, who is concerned with the ways in which manufacturing and information technologies are displacing industrial workers, argues that the forces behind this economic devastation of labor are actually being celebrated in a new political language of "virtual capitalism." That kind of talk, he notes,

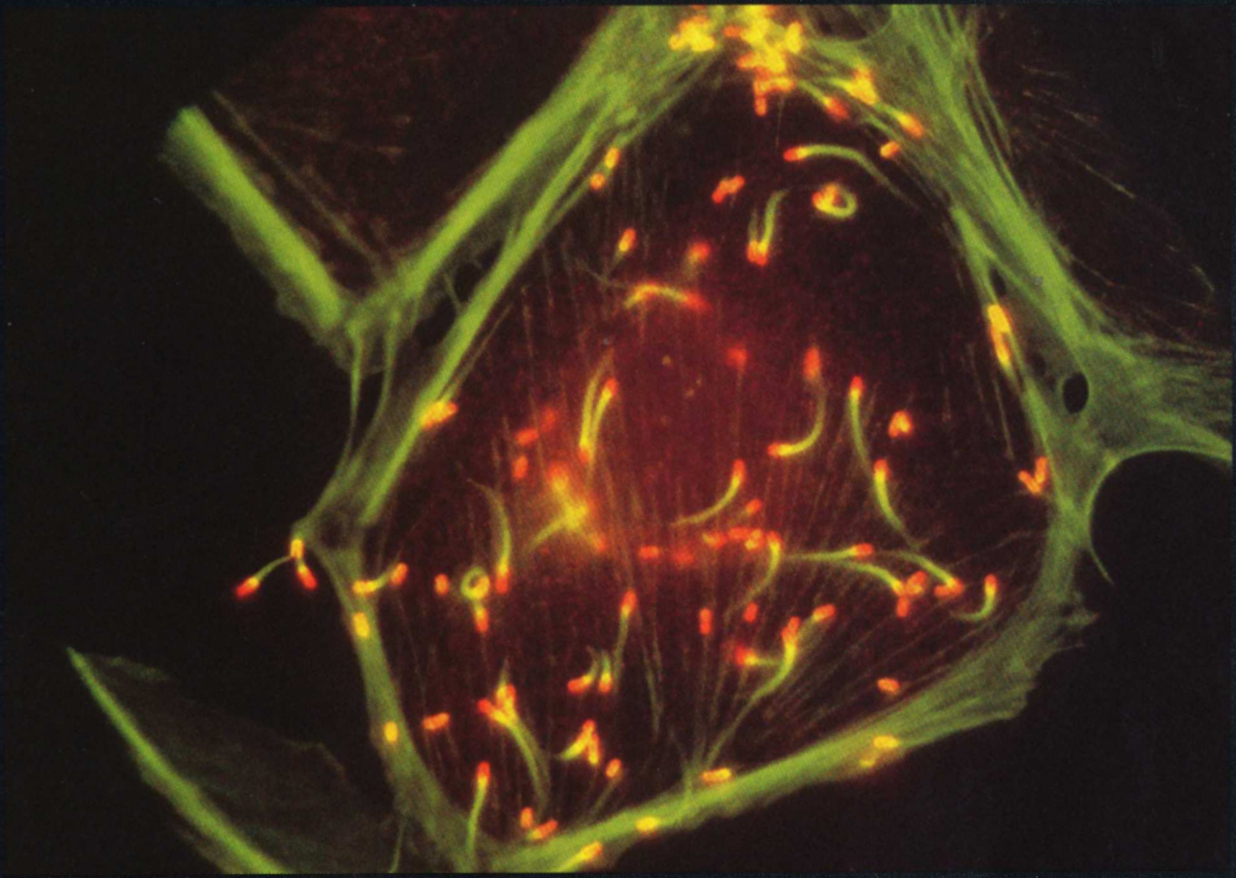
Classifieds

obsessively promotes computing and communications technology not only as a means for accumulating corporate profits but also as a "source of salvation from the reality of a lonely culture."

As a field, cultural studies does not simplistically oppose science and technology. It does, however, complicate our conventional wisdom, arguing that the styles of thinking that science and technology foster can have both desirable and undesirable, and predictable and ironic, effects. Sociologist Betina Zolkower makes this particularly clear in her essay "Math Fictions," which shows how textbook "story problems"—even the ones that attempt to avoid offending anyone—can still reflect cultural biases, perhaps by describing professional work schedules alien to inner-city youth. The elementary-school students who would solve those problems must participate in a vision of life about and from "elsewhere" while their social infrastructure decays, almost certainly deepening their feelings of alienation.

Taken together, these essays reflect an ethical commitment to illuminate the social implications of technology, and this spirit may help cultural studies weather *l'affaire Sokal*. Granted, the volume is not an easy read. Its wide scope will not appeal to everyone. Worse, there is enough jargon to satisfy the Sokalian cynics. But the reader's effort to understand the content largely pays off. One important role of critics is to serve as a kind of early-warning system, scanning the horizon for suspicious developments—and the critics represented here have indeed found such developments. We would do well to take heed.■

BRYAN C. TAYLOR is an associate professor of communication at the University of Colorado in Boulder.



A TALE OF COMETS—IN CELLS

Be the problem tuberculosis, pneumonia, or simply children's ear infections, antibiotic-resistant strains of bacteria responsible for such diseases continue to proliferate. Challenged by this public-health dilemma, scientists are searching for new ways to combat resilient bugs. Recognizing that one possible approach is to block their movement, cellular microbiologists are now monitoring bacterial pathways within host cells with a surprisingly familiar aid—video cameras.

In work as a research fellow at the MIT-affiliated Whitehead Institute for Biomedical Research, Julie A. Theriot has focused on the movement of two food-borne bacteria—*Shigella*, which causes dysentery, and *Listeria*, which triggers meningitis and stillbirths. She has found that after entering a host cell, these bacteria divide several times, then form "comet tails" that transport them directly among cells. This photograph shows the kidney cell of a kangaroo rat about four hours after it was injected with *Listeria*. Videos confirmed that proteins from both the bacteria's surface and the host cell cooperated in drawing thousands of filaments (shown as green) to the bacteria (red) and in forming the tails. The elongating tails nudge the pathogens into adjacent cells, spreading the infection.

In work with other microbiologists, Theriot, who has recently moved to Stanford University, is determining which genes produce the bacterial proteins and also isolating the host-cell proteins involved. These steps could help in figuring out how to stop comet tails from forming and bacteria from moving from one cell to another. That, in turn, might lead to a more effective disease-fighting strategy than continually updating the antibiotics now used against bacteria such as *Shigella*.—Mark Dwortzan

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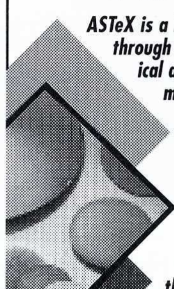

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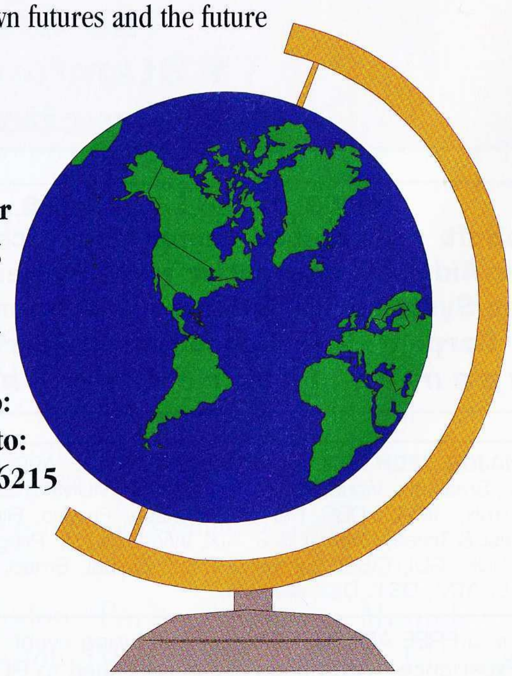

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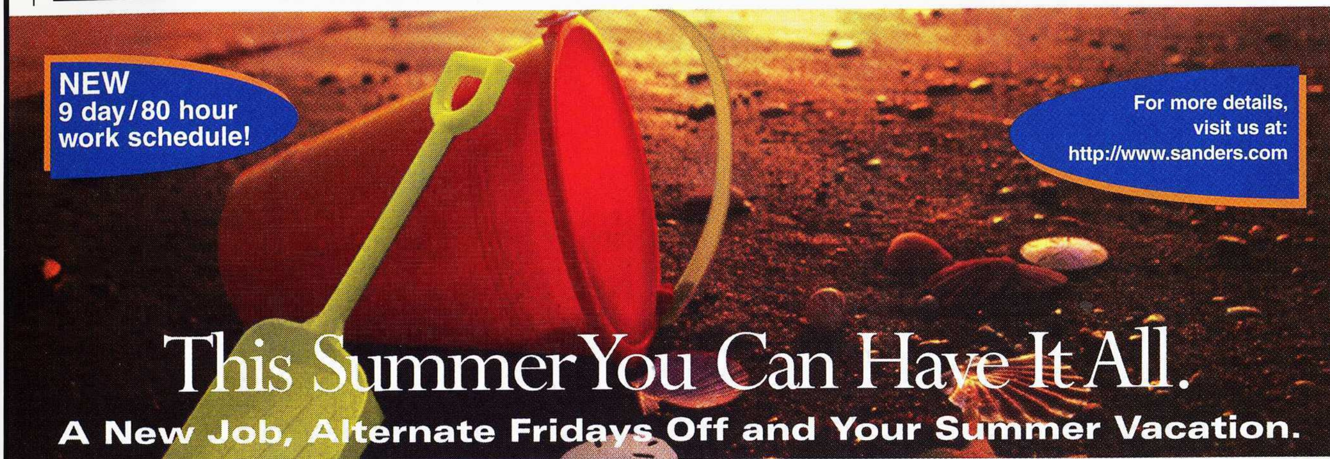

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